JOURNAL OF AGRICULTURAL RESEARCH

VOL. 39 WASHINGTON, D. C., JULY 15, 1929 No. 2

A PHYSIOLOGICAL STUDY OF ROOTING AND CALLUSING IN APPLE AND WILLOW [1]

By CHARLES F. SWINGLE [2]

Assistant Pomologist, Office of Horticultural Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

In treatises on horticulture but two categories of cuttings are generally recognized—those of softwood and those of hardwood. However, hardwood cuttings may, in turn, be divided into two categories—those that have preformed small but unmistakable root primordia (already present when the cuttings are removed from the original plant) and those that do not possess such primordia. Where they are found, these preformed primordia seem to be simply very small roots or groups of cells that will produce roots upon further growth. Little is known as yet about them or the environmental influences that affect their formation, but they appear to be specific or varietal characteristics of certain plant forms (*17*).[3] The present paper deals only with hardwood cuttings that have such preformed root primordia, apple cuttings (Springdale variety) and willow cuttings (*Salix alba* L.) being used.

Essentially, the rooting of cuttings with primordia consists simply in renewed growth, by which the small dormant roots elongate and push out beyond the bark. In the forms here studied the formation of these roots had occurred long before the cuttings were taken from the trees. These roots may be detected in the bark of 3-year-old and older branches of the Springdale apple, but they have not been observed in the younger wood. Apparently a certain degree of maturity is necessary before they begin to form.

The writer (*21*) has recently shown that such root primordia are formed by the cambium and apparently only at certain places where branch or leaf-trace parenchyma or primary or secondary rays cross the cambium. The primordia enlarge until the tips reach the outer surface of the bark or project a bit, and then they cease to enlarge and remain dormant until special conditions lead to renewed growth. They are apt to occur in small groups or in groups of 100 or even many more, as well as singly. The raised and modified areas of the bark in and beneath which they lie have long been called burrknots in

[1] Received for publication Mar. 13, 1928; issued July, 1929. This study represents one phase of nursery-stock investigations in the Bureau of Plant Industry of the U. S. Department of Agriculture. The work was done under the official direction of L. C. Corbett, Senior Horticulturist, in charge of the Office of Horticulture.

[2] For materials and equipment, for much help in planning and conducting the experiments, in interpreting the results, and in presenting them in this form, the writer wishes to express his appreciative thanks to Prof. Burton E. Livingston, Director of the Laboratory of Plant Physiology of the Johns Hopkins University. The writer has also been materially assisted from time to time by Dr. F. W. Hassis, of the same laboratory and of the U. S. Forest Service, and by Mrs. Mildred B. Swingle.

[3] Reference is made by number (italic) to "Literature cited," p. 127.

England. The occurrence and formation of root primordia in certain varieties of apple, etc., that exhibit this peculiar phenomenon have been reported by the writer (*17*, *18*, *19*, *20*).

The occurrence of preformed root primordia under the superficial bark layers in some willows has been demonstrated recently by Van der Lek (*11*) and by Priestley (*14*) and was mentioned by Trécul (*22*) in 1846. In the present studies these have not been given special attention further than to ascertain that they occurred on the willows used in the experiments and to make sure that the roots produced in these experiments were of the type here considered; that is, were actually produced by renewed growth of preformed, dormant roots. In willows, so far as known, there are no burrknots, for here the dormant roots occur only singly or in small groups and do not result in discernible enlargements. It appears, however, that *Salix alba* and the Springdale variety of apple are essentially alike in this particular, that both have preformed roots occurring in the bark of the older twigs. Vöchting (*23*) reported that root primordia were very much more numerous on stems of willow 2 years old and older than on the most recently formed stems.

ENVIRONMENTAL CONDITIONS NECESSARY FOR ROOTING AND CALLUSING OF CUTTINGS

The production of callus at the ends of cuttings or at lenticels often precedes or accompanies the "pushing" of roots. Callus is a form of tissue hypertrophy, sometimes resulting in large masses of white parenchyma, and it has been thought that there is some definite relation between callus production and root formation. It is still very generally held by propagators that new roots spring from the previously developed callus, in spite of the fact that Corbett (*4*) long ago pointed out that rooting and callusing are usually distinct processes. It seems probable, nevertheless, that roots may be induced to form from callus under some conditions.

Among the earliest analytical work on the rooting of cuttings were the important studies of Vöchting (*23*). According to his results with *Salix viminalis* L., gravitation had little or no influence on rooting, while light was found to retard it. His cuttings failed to root in the absence of oxygen.

Boehm (*1*, *2*) stated that the rooting of willow cuttings was greatly retarded or practically prevented when the air about them had a pressure of 3 to 6 atmospheres.

Simon (*15*) found that callus growth in *Populus nigra* L. was most vigorous with humidities of 85 to 90 per cent. Grau (*6*) reported that an air humidity of 85 to 95 per cent, with a temperature of 25° C., produced abundant callus but few stem growing points in decapitated cuttings and grafts of tomato and nightshade. With the same temperature, but with air humidity of 60 to 75 per cent, little callus was produced, but many stem growing points were formed. With a maintained air humidity of 76 per cent, she found that the optimum temperature for callus growth was about 28° to 32°, while that for the production of stem growing points was about 22° to 28°.

Curtis (*5*) obtained results which indicate that rooting was stimulated by proper treatment of the cuttings of *Ligustrum ovalifolium* Hassk. with potassium permanganate, probably through an acceleration of the respiration processes.

Zimmerman (*24*) reported that willow cuttings failed to root when surrounded by gas containing 90 to 100 per cent of oxygen. The most active rooting in his experiments occurred with a gas mixture of oxygen and nitrogen containing 15 to 33.3 per cent of oxygen. Approximately "normal" growth occurred with 25 per cent of carbon dioxide in the gas about the cuttings, provided the oxygen content was between 25 and 33.3 per cent. According to Zimmerman's experimental results, the optimum temperature for rooting for Late Crawford peaches seemed to be at least as high as 24° C., while the optimum for *Ilex verticillata* (L.) Gray seemed to be at least as high as 27°.

Regarding the influence of the hydrogen-ion concentration of the medium in which cuttings are rooted, apparently the only publications are those of Smith (*16*) and of Hitchcock and Zimmerman (*7*). The former worker found that Coleus cuttings rooted best in water with a pH value of 7.0 to 7.2, but there was some rooting throughout the range from pH 4.0 to pH 9.2. Inasmuch as acid peat with a pH value of about 4.6 is considered the best practical medium in which to root Coleus cuttings, she concluded:

> These results indicate that the free admission of air is one of the most favourable aspects of the fibre and suggest that (for this plant at least) given equal supplies of oxygen, a reaction of the medium near neutrality would be preferable.

Hitchcock and Zimmerman (*7*) presented at the 1926 meeting of the American Society for Horticultural Science some results showing that certain acid-soil plants root better in peat than in sand and that certain others root better in sand than in peat. In the discussion of their paper it was brought out, however, that they had been unable to differentiate between the influences exerted by acidity of the medium and its capacity to supply oxygen and water. It may be that the acidity of the medium as such plays very little part in the rooting of plant cuttings within the ordinary ranges of horticultural experimentation and practice.

Knight (*9*) has recently reported that the production of callus on cuttings is favored by a higher soil moisture than is required for the production of abundant roots. He does not appear to have distinguished between the influence of high water content as such and its influence in limiting the oxygen supply.

GENERAL NATURE OF THE EXPERIMENTAL STUDIES

The experiments reported in this paper represent an attempt to obtain some additional knowledge, of a somewhat quantitative nature, about the temperature, water, and oxygen relations of root and callus development on cuttings of the Springdale variety of apple and of *Salix alba* L. This study is distinctly of a preliminary nature. It is intended to report the results of a particular group of experiments with particular kinds of cuttings and should not be used as a basis for generalizations about the behavior of plant cuttings in general or even of cuttings with preformed, dormant roots.

Though this paper deals only with the controlling external factors, it is necessary to emphasize the obvious but frequently neglected or slurred generalization that the formation of roots clearly depends not on internal conditions alone nor on external conditions alone but on both categories of influential conditions operating together.

The experimental data were nearly all obtained in the Laboratory of Plant Physiology of the Johns Hopkins University in 1926–27, although some preliminary explorational tests had been made earlier.

METHODS AND PROCEDURES

THE PLANT MATERIAL AND ITS PREPARATION

The apple cuttings used in these experiments were all obtained from one tree of the Springdale variety at the Arlington Experiment Farm, Rosslyn, Va. The willow cuttings were obtained from one tree of *Salix alba* on the grounds of the Johns Hopkins University. Other plant material used from time to time was obtained at the United States Plant Field Station, Glenn Dale, Md. The willow cuttings were usually put into the experiment chambers the day they were removed from the tree. The apple cuttings were put into closed suitcases when removed from the tree and remained there, without the addition of water, for one or two days at a temperature of about 19° C., until they were placed in the chambers in water. In the case of the apple cuttings, as in the case of all other material not placed either in the chambers or in water as soon as removed from the plant, a fresh cut was always made at each end of each cutting.

In each experiment great care was taken to insure like lots of material of each kind for all tests throughout the series. After being made, the cuttings were sorted into as many lots as would be needed, all lots being as nearly alike as possible. The apple cuttings were from wood 3 to 10 years old; most of the willow cuttings were from 2-year-old wood, but some 1-year-old and some 3-year-old wood was used. In most of the experiments 50 cuttings were placed in each chamber, the chambers being 3-liter bottles. In some cases all cuttings in any chamber were of one kind, either apple or willow, but there were generally two or more plant forms represented in each chamber.

No precautions were taken to secure or maintain sterile conditions in the chambers. At the higher temperatures, especially with low rates of oxygen supply, considerable amounts of mold developed, and some fermentation was generally evident at the end of the 10-day experiment period. There were no indications, however, that lack of sterile conditions played any appreciable part in the control of rooting and callusing in any test.

In some of the experiments the cuttings were subjected to a preliminary treatment with water, and in about the same number of experiments they received no preliminary treatment. In most cases the experiment period was either 7 or 10 days, counting from the time the cuttings were made and distributed into groups.

EXPERIMENTAL CONDITIONS

In most cases the cuttings of each test were brought under the special conditions for that test by means of experiment chambers, large-mouth bottles, generally with a capacity of 3 liters, but in some cases larger or smaller. These test bottles were closed with rubber stoppers, suitably provided with perforations in cases where flowing gas was employed, and each bottle contained some water at the bottom. In some of the earlier experiments the bases of the cuttings

rested on wet or merely moist cotton, supported on miniature perforated tables formed from blocks of paraffin, which rested on the bottom of the bottle in each case. It was found, however, that this arrangement was unsatisfactory, since the bases of the cuttings were more or less unequally supplied with water by the cotton. In later experiments the cuttings were in contact with gas only, each one being supported on a wire stilt, applied just before the cutting was placed in the chamber. The stilt consisted of a piece of iron "stovepipe" wire wrapped once around the cutting near its base and projecting downward about 10 cm. beyond the lower end of the cutting. The free end of the wire rested on the bottom of the test bottle, and the cutting was supported so that no part of it came in contact with the water below.

The experimentation involved different treatments of the cuttings, with respect to (1) temperature, (2) water, and (3) oxygen conditions, which were more or less controlled artificially by special arrangements or procedures. The preliminary nature of the work and lack of time for further refinements made it undesirable or inexpedient to attempt precise controls, except in the case of temperature, which could be readily maintained within narrow limits of fluctuations. The influence of changing temperature was not studied, only continually maintained temperatures being employed.

TEMPERATURE

Most of the experimental results here reported were secured by means of a battery of seven dark chambers with automatically maintained temperatures. These temperature chambers have been described by Livingston and Fawcett (*12*). The seven chambers are vertical cylinders, each with a covered opening at the top, arranged in a row. Each chamber is surrounded by a water jacket, except above, where there is an insulating cover, and the water is mechanically stirred, which is also true of the air in the chamber. Each chamber is 33 cm. in diameter and 43 cm. deep. One end of the series is electrically heated and controlled; the other is electrically cooled and controlled. For each experiment the controls were set to give a series of seven different maintained temperatures. Temperature fluctuation in any chamber generally did not extend beyond 1° C. above and below the value shown, and fluctuation was usually much smaller. The largest fluctuations were of short duration; they were occasioned by necessary opening of the chambers and did not reach the cuttings in the test bottles.

The test bottles containing the cuttings were in the seven controlled chambers. When flowing gas was employed the tubes leading to and from the bottles entered the chamber through small holes in the top, alongside the removable cover.

Another arrangement for maintaining a single temperature on a very narrow temperature range was employed in some of the experiments. It consisted of a vertical, insulated, cylindrical tank of galvanized sheet iron, 70 cm. high and 50 cm. in diameter, filled with water and provided with a very positive mechanical stirrer operated by an electric motor, and also provided with an electric emersion heater, a mercury thermoregulator, and suitable relays. The test bottles containing the cuttings were suspended in the rapidly circulating water of the tank. No means was provided for cooling this tank,

and it was consequently used only for the maintenance of temperatures above the maximum one of the greenhouse room in which the apparatus was located.

A few experiments were carried out in the dark room of the laboratory, which provided a temperature generally about 19° C., with fluctuations between 18° and 22°.

Moisture

The moisture and conditions of the gas about the cuttings were those of approximate saturation for the temperature employed. As has been said, each test bottle had some water at the bottom. When flowing gas was employed the gas stream was first passed through water in a humidifying bottle, so that the gas entering the test bottle was practically saturated with water vapor. Upon entering, the gas bubbled through the standing water at the bottom of the bottle, and complete saturation was thus very nearly approached.

In some of the experiments the cuttings were inserted in the test bottles without any special preliminary treatment. Doubtless these cuttings had lost a little of their original water content, since they had been removed from the tree for a considerable period and had been brought into the warmer laboratory room from the cooler out of doors.

In some experiments the influence of preliminary wetting of the cuttings was studied. This preliminary treatment was applied just before the cuttings were placed in the test bottles, the aim being to increase more or less the water content of the cuttings, either throughout or near the cut ends or near the base alone. Several different preliminary treatments with water were employed, as shown just below and as summarized in the tabulated results. The time consumed in the preliminary treatment was, in every case, included in the 10-day period of the experiment.

(1) Cuttings were completely injected by being submerged in water, with the air above first nearly exhausted for 15 minutes and then allowed to reenter the injection chamber. They remained in the water 22 hours after atmospheric pressure had been resumed. (Experiment 8.)

(2) Cuttings were completely submerged in water for one hour without injection. (Experiment 14.)

(3) The bases of cuttings were submerged in water for 19, 22, 24, or 48 hours without injection. (Experiments 10, 9, 15, 16, respectively.)

(4) The bases only were injected (as in 1, above), and the bases remained under water for 19 hours after atmospheric pressure had been removed. (Experiments 11, 12.)

Oxygen

In many of the experiments gas flowed through the test bottles throughout the experiment. The gas stream was passed through the bottle by means of suitable tubes borne by a 2-hole rubber stopper set in the bottle mouth. The rate of flow was maintained by means of constant pressure and properly adjusted orifice resistance, a cotton-kaolin orifice control like that devised by Hutchins (*8*) being used.

Constant pressure was maintained by means of a mercury pressure regulator with 4 cm. of mercury column and continuous escape of some gas. Several rates of gas flow were employed, approximately as follows:

300 c. c. per hour (experiments 1 to 5 and experiment 7, apple and willow).
50 c. c. per hour (experiment 6, apple and willow).
200 c. c. per hour (experiments 8 to 16, apple, and experiments 8 to 12, willow).

Flowing air was employed in experiments 2 to 4 and 8 to 12 (apple and willow) and in experiments 13 to 16 (apple). Flowing oxygen was employed in experiments 1 and 7 (apple and willow), and an artificially prepared mixture of oxygen and nitrogen was employed in experiments 5 and 6 (apple and willow), the mixture containing 5 per cent oxygen. Glass and lead tubing were used, with a minimum amount of rubber tubing for connections. When flowing air was used the requisite pressure gradient was maintained by means of an ordinary water aspirator pump attached to the laboratory water supply, the mercury pressure regulator and the orifice controls being suitably arranged. Air entered each test bottle from the maintained-temperature chamber in which the bottle stood, the air being thus at the proper temperature in each case, and it was discharged throughout the aspirator. When flowing oxygen or the artificial mixture of oxygen and nitrogen was used it was drawn from an ordinary commercial tank by means of a control valve, no pump being required.

The oxygen-nitrogen mixture was prepared in a commercial gas tank at high pressure, the proportions of the two gases being determined by their partial pressures in the mixture. The method used for preparing this mixture was that employed by Prof. E. K. Marshall, of the Johns Hopkins Medical School, who brought it to the writer's attention. In one case, for example, an empty tank was connected to a tank of nitrogen at an initial pressure of 1,800 pounds per square inch, the connection being made by means of a piece of suitable copper tubing 75 cm. long with a mechanical pressure gauge inserted in the middle and with a suitable coupling at each end. After the two tanks had been connected their valves were opened, and the pressure was allowed to become about the same in both. Both valves were then closed, and one tank was removed from the connecting tube and replaced by a tank of oxygen at a pressure of 1,200 pounds per square inch. After an hour, during which the nitrogen (cooled by this expansion) again assumed the temperature of the surroundings, the valve on the nitrogen tank was opened (the valve on the oxygen tank remaining closed), and the pressure of the nitrogen was read from the gauge; it was 910 pounds per square inch. Then the oxygen valve was opened, and oxygen was allowed to pass into the nitrogen in several installments till the gauge reading, with the oyxgen valve again closed and after a suitable period for temperature recovery, was 958 pounds per square inch. Then both valves were closed, and the coupling tube was removed. The tank that had been originally empty now contained a mixture of nitrogen and oxygen, with partial pressures of 910 and 48 pounds per square inch, respectively; i. e., a mixture of approximately 95 per cent of oxygen. This method of preparing the gas mixture does not involve differential solubilities of the gases in a liquid, as when gasometers are used, and it

provides the mixture conveniently in a pressure tank, under pressure suitable for long runs of such experiments as are here considered. The limits of precision are set by the precision of the gauge readings.

Commercial nitrogen and oxygen such as were used in these studies are prepared by the distillation of liquid air and may be supposed to contain some impurities, which are limited to the constituents of air. The nitrogen contains a very little oxygen (perhaps 0.5 of 1 per cent), and the oxygen contains a corresponding amount of nitrogen. Carbon dioxide and argon are present in such small quantities that they may be ignored. Since tests of similar gases by other workers indicate no other impurities as likely to be present, no scrubbing arrangements were employed, and no analyses were made.

When only small quantities of gas mixtures were needed, other and less precise methods of mixing were employed. The ordinary procedure with a water gasometer was followed in some cases. In some of the preliminary experiments without maintained temperatures and without flowing gases, rubber bladders were used, the gas within the test bottle being thus maintained under slightly more than atmospheric pressure. With this arrangement, which was similar to that used by Free,[4] only nitrogen, oxygen, or carbon dioxide was used with any given bottle and bladder, and mixtures were not attempted. In a few experiments a method described by Cannon (*3*) was employed. The oxygen of the air in an inverted test tube was practically all removed very rapidly by means of moist, bright steel wool in the closed end of the tube, the cuttings being initially placed in the tube and the lower end of the latter being closed with agar gel.

Duration of the Tests

It has been made clear by the work of Lehenbauer (*10*) on maize seedlings that the temperature graph for any form of plant growth may be expected to vary considerably with the length of the experiment period, especially with regard to the cardinal temperatures. If the period is very short, no growth is to be detected except at temperatures within or in the vicinity of the optimum range. This generalization probably applies to the study of the rooting and callusing of cuttings. A 10-day period was arbitrarily adopted for most of these tests, simply because this period proved long enough to give apparently satisfactory and consistent results. A 7-day period was used for some of the experiments with willow, especially those carried out in the single-chamber apparatus described above, maintained only at optimal or supra-optimal temperature.

Observations and Records

At the end of the 10-day period the cuttings were all removed from the test bottles and records were made of the amount of rooting and callusing that had occurred. The data thus secured were so averaged as to give a numerical index representing each form of activity at each temperature of an experiment. For callusing, observations were made on base and top callus separately.

[4] Free, E. E. The oxygen requirement of plant roots in relation to soil aeration. (Diss. Johns Hopkins.) 1917. [Unpublished.] (See also reference *13*, p. 128.)

EXPERIMENTS WITH APPLE CUTTINGS

The data from the experiments on rooting and callusing of apple cuttings in flowing gas and with maintained temperatures are presented in Table 1. For each temperature used (except the highest in each experiment) the tabulation shows an index value representing the "pushing" of roots and two values for the formation of callus, the first for the tops and the second for the bases of the cuttings, which were all placed with their basal ends downward. For the highest temperature value in each series no rooting or callusing values are given, since no activity of either sort was observed at these temperatures. Consequently, the temperature shown at the extreme right in each line of the table may be taken to represent either the temperature maximum for all three kinds of activity in the experiment in question or else a value somewhat higher than the maximum in each case.

The values given for pushing of roots represent in each instance the proportion of the cuttings used that showed more or less pushing of roots at the end of the 10-day period. These are calculated on the basis of 10; the value 10 indicates that every cutting showed some pushing of roots, the value 6 indicates that six-tenths of the cuttings showed this activity, and so on. These rooting values give no indication of the number of protruding roots observed or the lengths of the roots. If a cutting showed but a single slightly protruding root it was recorded as pushing, and the record was the same if there were several protruding roots, some of which were 1 cm. or more in length. It would doubtless have been more to the point if the number of root primordia had been determined for each cutting together with the number and length of the protruding roots at the time of observation, so that the index of pushing might have been based on the total number of primordia available instead of on the number of cuttings used, while the amount of growth after the roots emerged might have been shown quantitatively in terms of their elongation. In the case of the willow cuttings, however, the counting of primordia would not have been possible for these are not visible.

The amount of callus developed at the top and at the base of the cuttings during the 10-day period is shown in the table by relative numerical values between 0 (no callus observed) and 10 (the maximum amount of callus observed in this entire study). The amount of callus formed per cutting was not measured precisely, and these data are based on a somewhat rough scoring method that was developed during the progress of the studies. The score value 10 indicates that the region of the cutting considered (top or base) was about half covered with thick, apparently vigorous callus.

TABLE 1.—*Numerical values for pushing of roots and for growth of callus of apple cuttings*

Experiment No.	Date started	Conditions	Temperature	Roots [a]	Callus [b] Top	Callus [b] Base	Temperature	Roots [a]	Callus [b] Top	Callus [b] Base	Temperature	Roots [a]	Callus [b] Top	Callus [b] Base	Temperature	Roots [a]	Callus [b] Top	Callus [b] Base	Temperature	Roots [a]	Callus [b] Top	Callus [b] Base	Temperature	Roots [a]	Callus [b] Top	Callus [b] Base	Highest temperature, no growth
	1926		° C.				° C.				° C.				° C.				° C.				° C.				° C.
1	Nov. 8	Flowing O_2; bases on damp cotton	7.7	0	0	0	14.7	1	(c)	(c)	20.7	6	(c)	(c)	27.7	7	(c)	(c)	34.1	5	(c)	(c)	39.8	0	0	0	46.5
2	Nov. 23	Flowing air; bases on damp cotton	13.2	0	0	0	17.2	0	0	0	21.9	2	(c)	(c)	25.7	6	(c)	(c)	31.3	6	2	3	36.0	3	(c)	(c)	40.7
3	Dec. 7	Flowing air; bases on wet cotton	14.1	0	0	0	17.8	0	0	0	22.1	0	0	0	25.5	0	0	0	30.3	4	2	0	35.3	0	0	0	40.2
4	...do	Flowing air; bases on wire stilts	14.1	0	0	0	17.8	0	0	0	22.1	2	4	4	25.5	5	5	5	30.3	7	4	4	35.3	4	3	3	40.2
	1927																										
5	Jan. 5	Flowing 5 per cent O_2, fast; stilts	13.3	0	0	0	16.7	2	0	1	20.6	4	0	4	23.6	8	6	9	28.6	5	6	9	32.8	1	6	8	37.9
6	...do	Flowing 5 per cent O_2, slow; stilts	13.3	0	0	0	16.7	1	0	1	20.6	3	0	2	23.6	7	5	8	28.6	7	6	9	32.8	0	3	5	37.9
7	Jan. 21	Flowing O_2; stilts	14.4	1	0	0	17.9	1	0	0	21.7	2	0	1	24.8	6	1	2	29.7	6	2	3	33.8	5	0	1	38.8
8	Feb. 3	Flowing air; stilts; injected; completely soaked 22 hours	14.2	2	0	0	17.7	1	0	0	21.4	2	0	0	24.5	0	0	0	29.6	0	0	0	33.7	0	0	0	39.0
9	...do	Flowing air; stilts; bases soaked 22 hours	14.2	9	0	0	17.7	8	0	2	21.4	10	2	4	24.5	10	5	5	29.6	10	5	6	33.7	9	2	3	39.0
10	Feb. 15	Flowing air; stilts; bases soaked 19 hours	12.4	8	0	0	16.2	10	0	0	20.3	9	0	4	23.4	9	0	4	28.6	10	5	6	32.8	10	3	5	37.6
11	...do	Flowing air; stilts; bases injected; soaked 19 hours	12.4	8	0	0	16.2	8	0	0	20.3	9	0	2	23.4	9	0	4	28.6	10	5	7	32.8	8	0	0	37.6
12	...do	...do	12.4	7	0	0	16.2	9	0	0	20.3	10	0	3	23.4	9	0	4	28.6	10	5	6	32.8	9	5	5	37.6
		Average of 11 and 12	12.4	7.5	0	0	16.2	8.5	0	0	20.3	9.5	0	2.5	23.4	9	0	4	28.6	10	5	6.5	32.8	8.5	2.5	2.5	37.6
13	Feb. 26	Flowing air; stilts	12.2	5	0	0	16.2	9	0	3	20.3	7	2	6	23.7	10	6	8	28.7	8	6	9	32.8	8	4	6	38.0
14	...do	Flowing air; stilts; completely soaked 1 hour	12.2	10	0	0	16.2	9	0	0	20.3	10	2	5	23.7	10	4	6	28.7	10	8	9	32.8	10	0	3	38.0
15	...do	Flowing air; stilts; bases soaked 24 hours	12.2	4	0	0	16.2	8	0	3	20.3	10	2	3	23.7	10	3	3	28.7	10	5	2	32.8	4	0	0	38.0
16	...do	Flowing air; stilts; bases soaked 48 hours	12.2	4	0	0	16.2	8	0	0	20.3	10	0	0	23.7	10	0	0	28.7	8	5	2	32.8	0	0	0	38.0

[a] The figures in this column represent the proportion of cuttings that showed some pushing of roots at the end of 10 days. The values are calculated on the basis of 10.

[b] The figures in these columns represent the total amount of callus shown by the cuttings in each lot (not the number of cuttings that showed some callus), based on an arbitrary scale. The highest value shown (10) indicates all the cuttings in the test were about half covered at the cut end with vigorous callus.

[c] No observation.

Besides the experiments with both flowing gas and seven different maintained temperatures, several experiments were carried out with other treatments. The results of some of these additional experiments are given hereinafter in Tables 3, 4, and 5. Table 3 presents the numerical results of experiments 17, 18, and 19, with maintained temperatures but without flowing gas. These results are arranged like those in Table 1 except that values for lenticel callus-formation are here included. The latter values are based on a scale of 10 like those for top and base callus formation. Table 4 gives the rooting score values from experiments 20 to 23, with different treatments, conducted in a series of four chambers and in the laboratory dark room. In two other dark-room experiments, sealed chambers of different capacities were used, the chambers of experiment 24 being filled with air and those of experiment 25 being filled with oxygen at the start. The numerical values for rooting and callusing from these experiments are given in Table 5, on a scale of 10, just as in Tables 1, 2, and 3.

The data given in the tables will be generally discussed with reference to temperature graphs that have been drawn to represent each series.

ROOTING OF APPLE CUTTINGS

Experiments with Flowing Gas and Seven Different Maintained Temperatures

This section deals with the data given in Table 1 and with the corresponding graphs. (In all the charts, figs. 1 to 17, the numbers on the ordinate indicate relative degrees of rooting or callusing on a scale of 10.) Experiment 1, started November 8, 1926, gave what appears to be the usual form of temperature curve for growth, with minimum about 8° C. or higher, maximum about 39° or lower, and optimum about 28°. (Fig. 1.) These cuttings were well supplied with water-saturated oxygen, and the bases were not covered by water, for the cotton on which they rested was not nearly saturated. It is possible, however, that some water was absorbed from the damp cotton. Experiment 2 (fig. 1), started November 23, 1926, was like experiment 1, except that air instead of oxygen was continually supplied. The temperature maximum here is indicated as below 41°, and it may have been about 39° or lower, as in experiment 1. The optimum for experiment 2 is not so clearly shown as that for experiment 1, but it may have been about the same temperature as that for experiment 1 or somewhat higher. Experiment 2 differed from experiment 1, however, with respect to the minimum, which appears to have been above 18°, perhaps even about 20°. No explanation of this difference is apparent, for it seems hardly probable that the lower oxygen supply of the second series could have retarded

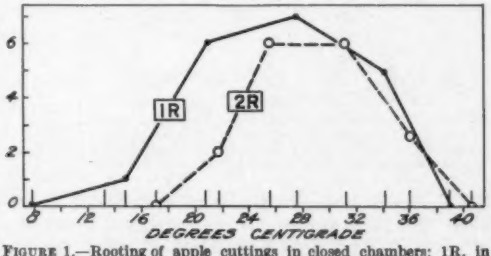


Figure 1.—Rooting of apple cuttings in closed chambers: 1R, in flowing oxygen; 2R, in flowing air

root pushing for the lower temperatures without showing a still more marked retardation for the higher ones. The dates are nearly the same for the two experiments, and seasonal differences can hardly be considered as explaining the observed differences.

Experiments 3 and 4 (fig. 2) were planned to compare the behavior of cuttings with bases surrounded by wet cotton with that of other cuttings with bases in water-saturated air, both series being otherwise alike, continually supplied with flowing air. It appears that the wet cotton wrappings at the bases of the cuttings retarded the pushing of the roots (fig. 2, 3R), for no roots emerged except at temperatures about 30° and 35° C.; furthermore, emerging roots were here confined to the upper half of the cuttings, and the amount of root growth was noted as very slight. The minimum in this case seems to have been above 26°, the maximum below 40°, and the optimum perhaps about 34° or 35°. In experiment 4, however, with no water films about the bases, the growth curve indicated is of the usual form, with minimum about 18° and maximum below 40°, while the optimum is indicated in this case as about 30°, though it may have been lower. This graph for experiment 4 is similar to that for experiment 2, which had similar conditions. It is remarkable that the more plentiful oxygen supply of experiment 1 seems to have accelerated the pushing of roots at the lower temperatures, giving a much lower apparent minimum than that shown for experiments 2 and 4. If it be supposed that the wet cotton of experiment 3 acted to retard the access of oxygen to the cuttings, then it may be significant that this wet-cotton treatment appears, when compared with experiment 1, to have produced a retardation similar to that of experiments 2 and 4 but still more pronounced.

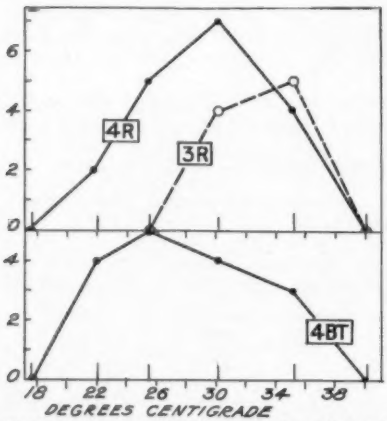


FIGURE 2.—Rooting (3R and 4R) and base-callus and top-callus formation (4BT) of apple cuttings in closed chambers with flowing air; 3R, bases of the cuttings resting on wet cotton; 4R, bases resting on wire stilts

In Figure 3 are presented this comparison between the data for experiments 2 and 4 (considered as alike) on the one hand and experiment 13 on the other, which indicates a pronounced difference that may be related to the seasons of the year at which the experiments in question were begun. The lower graph of the upper part (2, 4R) represents the average of experiments 2 and 4 (November 23 and December 7), and the upper graph (13R) represents experiment 13 (February 26). With respect to external conditions these two graphs represent no considerable differences, and the marked difference shown seems to have been due to changes that had occurred in the twigs themselves between November and March. It appears that the optimum temperature was definitely lower (about 24° C.) and that the graph was much flatter at the top for the later experiment, and also that the minimum was much lower (probably below 10°

and perhaps as low as 9°). The maximum temperature appears to be about the same for both seasons (about 40°).

Experiments 5 and 6 (fig. 4) were characterized by a low oxygen content in the flowing gas (5 per cent of oxygen and 95 per cent of nitrogen) and were planned to bring out a comparison between rapid and slow flow, the rate of flow for the gas mixture being only one-sixth as rapid for experiment 6 as for experiment 5. The oxygen supply for experiment 5 was lower than that for experiments 2, 3, and 4 (with flowing air) and much lower than that for experiment 1 (with flowing oxygen). The graphs of experiments 5 and 6 agree very closely. Apparently these two sets of conditions were too nearly alike to bring out significant differences in the pushing of the roots. Only with respect to the maximum temperature do these graphs disagree, and it is to be noted that, although no pushing was observed at about 33° C. in experiment 6, yet the amount of pushing for this temperature in the other experiment was very small. If the two series are considered together, the minimum may be estimated as above 14°, the maximum as about 34°, and the optimum as about 24° to 26°. Apparently the low concentration of oxygen here acted chiefly to reduce the index values for the supra-optimal temperatures and to shift the maximum toward the left.

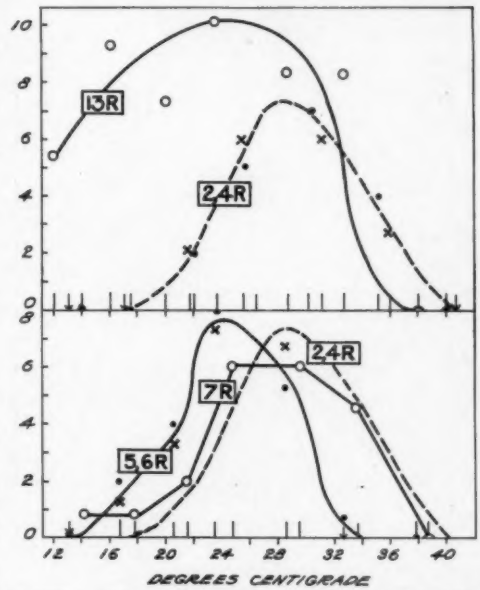


FIGURE 3.—Upper portion: Seasonal differences in the rooting of apple cuttings in closed chambers with flowing air. Lower portion: Rooting of apple cuttings in closed chambers with different flowing gases, experiments 2 and 4, air; 5 and 6, 5 per cent oxygen in nitrogen; 7, oxygen

Experiment 7 (fig. 3, lower part; fig. 5, upper part) resembled experiment 1, but the cuttings of the later series were entirely surrounded by moist gas (being supported on wire stilts) while those of the earlier series rested on damp cotton. The two experiments agree in respect to the cardinal temperatures (about 8°, 28°, 39° C.), but the values for rooting are higher for experiment 1 in the intermediate suboptimal temperature range. It is not easy to relate this difference to the seasonal difference between these two series, for it is in the opposite direction from that shown between experiments 2 and 4 on the one hand and experiment 13 on the other. Experiments 2, 4, and 13 were with flowing air, while experiments 1 and 7 were with flowing oxygen, but this circumstance can hardly give a clue to an explanation of the observed difference between the results of the two

series. It is suggested that the difference between the graphs for experiments 1 and 7 may be related to water supply, for the cuttings of the earlier series rested on damp cotton, whereas those of the later series were entirely surrounded by moist gas, as has been noted. However, the remarkable similarity of the graphs for experiments 2 and 4 render such an explanation at least doubtful, unless the difference between flowing air and flowing oxygen is considered as influential in this respect, for the cuttings of experiment 2 had the same moisture treatment as those of experiment 1, and the cuttings of experiment 4 had the same moisture treatment as those of experiment 7. The difference between the graphs for experiments 1 and 7 were related to unknown conditions.

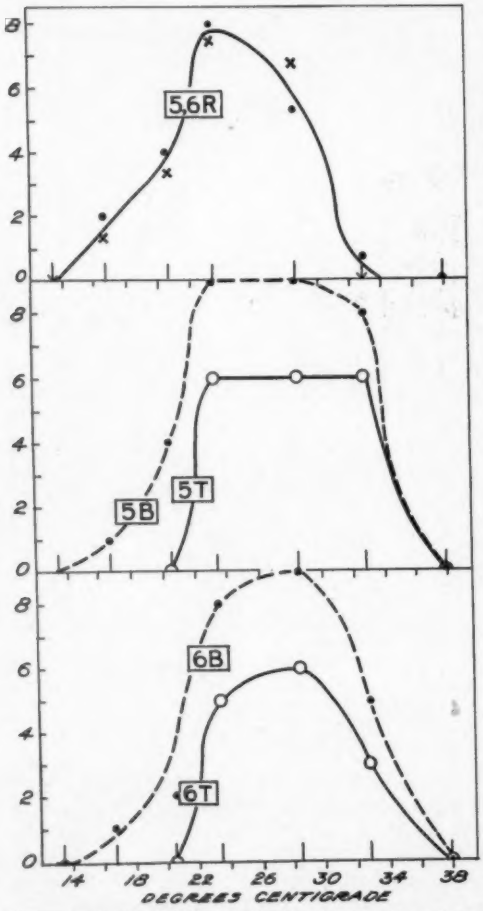


FIGURE 4.—Rooting (5, 6 R), top-callus formation (5T, 6T), and base-callus formation (5B, 6B) of apple cuttings in closed chambers in a flowing-gas mixture of 5 per cent oxygen in nitrogen. Experiment 5, 300 c. c. gas per hour; experiment 6, 50 c. c. per hour

Experiments 8 and 9 (fig. 6, upper part) were alike except for preliminary water treatment, both having flowing air. For experiment 8 the cuttings had been first injected and then completely submerged in water for 22 hours. For experiment 9 they had not been injected, and only the bases had been submerged during a soaking period of 22 hours. It is clear that the more abundant water treatment in experiment 8 greatly retarded the pushing of roots and completely inhibited it for temperatures above about 24° C.

The graph for experiment 9 has a very flat-topped form, indicating a broad range of approximately optimal temperatures. An optimum temperature in this case can not be estimated; it is represented by a range from about 14° to 34° C. No minimum temperature was

reached, but it must be estimated as probably as low as 8° or 9°, and the maximum was about 39°.

The exceptionally broad optimal range shown by the values from experiment 9 suggests that some special preliminary water treatment may be regarded as beneficial, although it must not be too extensive. Experiments 10, 11, and 12 (fig. 7, upper part), the last two being duplicates, gave graphs essentially much like that for experiment 9 and appear to support this suggestion. All had preliminary water treatment, and the optimal range seems to have extended from about 16° to about 29° C., if the results of the three tests are combined. Soaking alone (experiment 10) gave the broader optimal range, while an injection at the beginning of soaking seems to have narrowed this range somewhat at both ends. Experiments 9, 10, 11, and 12 appear to show that rooting in February was not much influenced by temperature differences between about 16° and 33° when some extra water was added to the tissues by preliminary water treatment. But the data from experiment 8 indicate, as has been said, that such preliminary water treatment may be excessive, resulting in a pronounced retardation and even in a complete inhibition of the pushing of roots. It may be that the internal water supply was somewhat inadequate in the cuttings used at that time, unless preliminary water treatment had been given. The retarding action of excessive preliminary treatment with water may have been due to a water plugging of air spaces in the tissues of the cuttings, this plugging perhaps operating to retard the supply of oxygen to the root primordia.

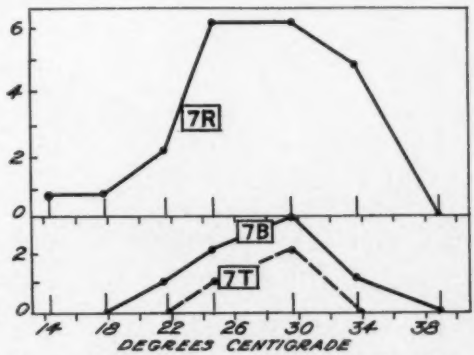


FIGURE 5.—Rooting (7R), top-callus formation (7T), and base-callus formation (7B) of apple cuttings in closed chambers with flowing oxygen

The growth values for the optimal temperatures were very high (9) in these experiments, as well as in experiment 9. As to the indications regarding the minimum and maximum temperatures, experiments 9, 10, 11, and 12 suggest a low minimum, hardly above 8° or 9° C., while they agree very well in indicating a maximum of about 38° to 39°.

Experiments 13, 14, 15, and 16 (figs. 8 and 9) were all carried out at the same time, beginning February 26, 1927, and all had the same gas treatment (flowing air). They were planned to throw more light on the relation of root pushing to preliminary water treatment. The cuttings of experiment 13 were without such treatment, while those of the remaining tests received different water treatments. If the graph of experiment 13 is employed as a standard for comparison, the graphs of Figure 8 indicate that the optimal range was markedly widened by completely soaking the cuttings one hour at the start of the test. This range and the form of the temperature graph were

not markedly altered from those shown for experiment 13 by a preliminary soaking of the bases of the cuttings for 24 hours (experiment 15), and the range was much shortened and the graph was also much depressed (for the supra-optimal temperatures) when the bases were soaked for a preliminary period of 48 hours (experiment 16).

It appears that these cuttings, made February 26, were greatly improved with regard to rooting at suboptimal and supra-optimal temperatures (with flowing, water-saturated air) if they had been given the preliminary water treatment of experiment 14, that they were not seriously affected by the treatment of experiment 15, but that the water treatment of experiment 16 was markedly excessive (with consequent retardation) for temperatures above about 26° C. These tests seem to strengthen the suggestion derived from experiments 8 to 12. When the soaking at the bases of the cuttings was limited to a period of 24 hours, it appears that the favorable influence of preliminary soaking (perhaps due to a resulting increased water content of the cuttings) nearly offset a concomitant unfavorable influence (perhaps related to decreased oxygen supply), but that when soaking was prolonged to 48 hours the unfavorable influence greatly predominated, especially for supra-optimal temperatures.

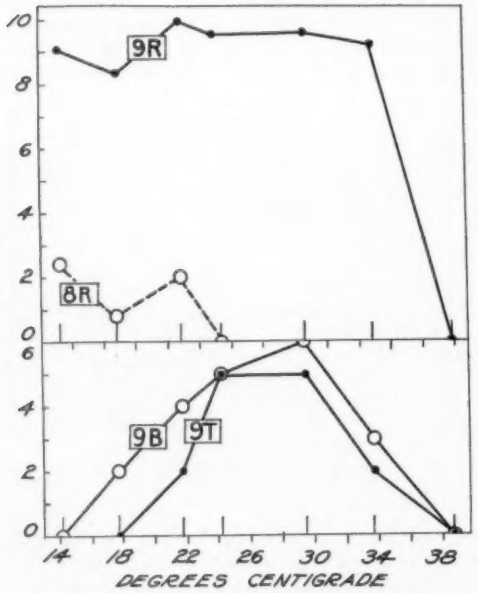


FIGURE 6.—Rooting (8R, 9R), top-callus formation (9T), and base-callus formation (9B) of apple cuttings in closed chambers with flowing air. The cuttings of experiment 8 were injected with water and remained completely immersed for 22 hours, while those of experiment 9 were soaked in water (bases only) for same length of time

The results of these last four experiments agree in general with those of experiments 9, 10, 11, and 12, in showing very high values (10) for the indices of rooting activity. They also agree in indicating low minimal temperature values (below 8° C. for experiment 14) and in indicating a temperature maximum about 38° (except for experiment 16, with excessive preliminary water treatment, for which the temperature maximum appears to have been in the vicinity of 33°).

In addition to the numerical data taken from line 15 of Table 1, and represented by the upper line of the upper portion of Figure 10, the lower line1 (4r) of the same figure shows an estimate of the actual temperature curve of root pushing based upon additional observations made at the completion of experiment 14. It was noted that the largest number of roots per cutting and the greatest growth in length

occurred at about 23.7° C. and at about 28.7°. At these temperatures almost every available primordium was observed to be pushing, and roots 2 or 3 cm. in length were evident in many cases. The same amount of root growth was evident for 23.7° and for 28.7°, but roots were fewer and shorter at a temperature of 32.8° and at temperatures of 20.3° and lower; however, as has been stated, some root growth was observed on nearly every cutting. Similar qualitative estimates on number of roots per cutting and average root length were made at the completion of experiment 9 (bases soaked 22 hours) and experiments 10, 11, and 12 (bases soaked 19 hours). In all of these five experiments it was observed that the amount of growth in length as well as the proportion of available primordia that had pushed seemed to be the same at about 24° and about 29°.

Although no cuttings were tested at temperatures below 12° C. in experiment 14, the graph for this experiment (fig. 10, 14r) is extended to the zero line at 9°, for while every cutting subjected to a temperature of about 12° showed some root activity, such activity was so slight as to indicate that the zero point for discernible root growth within 10 days was not far from 9°.

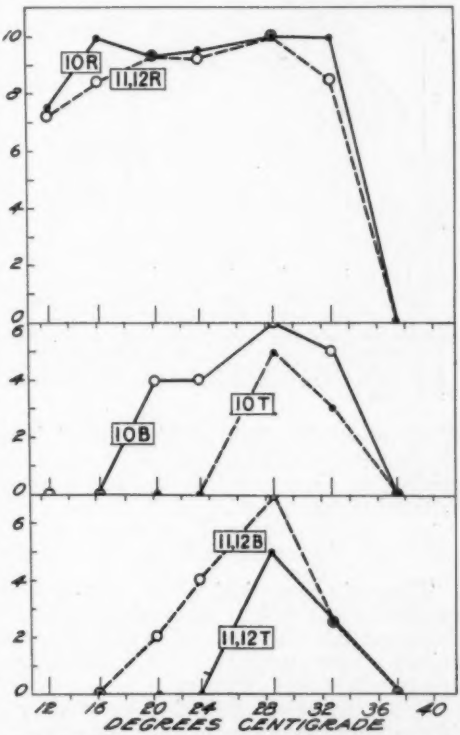


FIGURE 7.—Rooting (10R, 11, 12R), top-callus formation (10T, 11, 12T), and base-callus formation (10B, 11, 12B) of apple cuttings in closed chambers with flowing air. Experiment 10, bases of cuttings soaked 19 hours; experiments 11 and 12, bases injected with water and soaked 19 hours

It is possible from these 16 experiments to assign 41° C. as the upper temperature limit at and beyond which no root pushing took place, but no definite minimum is apparent. Although the number of roots per cutting was small and the growth in length was very slight, nevertheless a very slow growth rather than the complete stopping of growth seemed to be indicated for the lowest temperatures tested. In fact, subsequent results showed that the absolute minimum temperature for pushing of roots was below 4.5°. Branches from 1 to 2.5 meters long were cut from the tree on February 23 and were placed with their bases in water, and when these were examined May 14 they showed a very slight amount of pushing by almost every avail-

able primordium except those actually in the water. Nevertheless, growth of buds seemed to have been entirely stopped at this temperature.

A comparison of the graph of experiment 13 with the corresponding one of experiments 2 and 4 (see fig. 3) indicates, as has been noted, that the results of the later series differed from those of the earlier ones by showing a much greater rooting activity for the maintained temperatures below about 30° C. This apparent seasonal relation (perhaps due to differences in what may be termed the physiological maturity of the root primordia and their surrounding tissues) seems to have resulted (1) in shifting the later optimal temperature (experiment 13) downward on the temperature scale from about 30° to about 24°, (2) in shifting the minimum temperature in a similar manner (from about 18° to 8° or 9°, or lower), and (3) in markedly raising the index values for all temperatures below the supra-optimal temperatures.

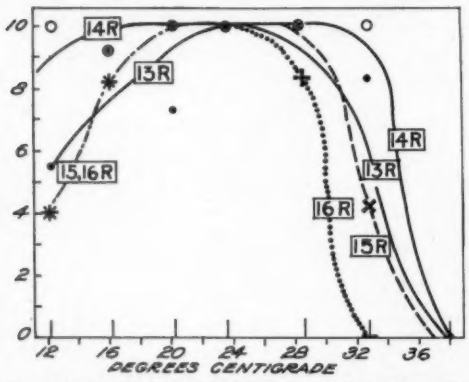


FIGURE 8.—Rooting of apple cuttings in closed chambers with flowing air and with different water treatments: Experiment 13, no water treatment; experiment 14, material completely soaked 1 hour; experiment 15, bases soaked 24 hours; experiment 16, bases soaked 48 hours

SUMMARY OF RESULTS OF EXPERIMENTS 1 TO 16

The main numerical results of the several series are brought together for convenient comparison in Table 2, which is arranged to bring out the relations with regard to the degree of rooting for maintained temperatures near the optimum and with regard to the water treatment.

The later series, beginning on or after February 3, all gave very high values for the index of rooting (9 or 10) for the optimum temperature, with the single exception of experiment 8, the cuttings of which apparently had had excessive preliminary treatment with water. None of the earlier series gave index values higher than 8, no matter what the treatment. On the other hand, none of the earlier series gave these values lower than 6, except when the bases of the cuttings rested on wet cotton (experiment 3, with index value of 5). While this evidence is not very pronounced, it suggests that these cuttings had a somewhat greater tendency to root, under the range of conditions tested, in the latter part of the season than they had in the earlier part.

TABLE 2.—*Summary of results of experiments 1 to 16 in rooting and callusing of apple cuttings*

Experiment number	Date started	Flowing gas	Water conditions	Data for rooting: Approximate cardinal temperatures: Minimum	Data for rooting: Approximate cardinal temperatures: Optimum	Data for rooting: Approximate cardinal temperatures: Maximum	Data for rooting: Index for optimum temperature	Data for top callus: Approximate cardinal temperatures: Minimum	Data for top callus: Approximate cardinal temperatures: Optimum	Data for top callus: Approximate cardinal temperatures: Maximum	Data for top callus: Index for optimum temperature	Data for base callus: Approximate cardinal temperatures: Minimum	Data for base callus: Approximate cardinal temperatures: Optimum	Data for base callus: Approximate cardinal temperatures: Maximum	Data for base callus: Index for optimum temperature
				°C.	°C.	°C.		°C.	°C.	°C.		°C.	°C.	°C.	
1	1926 Nov. 8	Water saturated O_2	Bases on damp cotton	8	28	39	7	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
7	1927 Jan. 21	do	Cuttings not in contact with liquid water.	8(?)	28	39	6	22	30	34	2	18	30	38	3
		Water-saturated mixture:													
5	Jan. 5	5 per cent O_2	do	14	24	34	8	20	24–35	38	6	14	24–29	38	9
6	do	95 per cent N_2	do	14	24	34	7	20	29	38	6	14	29	38	9
4	1926 Dec. 7	Water-saturated air	do	18	30	40	7	18	26	40	5	18	26	40	5
13	1927 Feb. 26	do	do	9(?)	24	38	10	16	24–29	38	6	12	29	38	9
2	1926 Nov. 23	do	Bases on damp cotton	18	28	40	6	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
14	1927 Feb. 26	do	Completely soaked 1 hour	8(?)	14–32	38	10	16	29	33	8	16	29	38	9
10	Feb. 15	do	Bases soaked 19 hours	8(?)	16–33	38	10	23	29	38	5	16	29	38	6
9	Feb. 3	do	Bases soaked 22 hours	8(?)	14–34	39	10	18	24–30	39	5	14	30	39	6
15	Feb. 26	do	Bases soaked 24 hours	9(?)	20–29	38	10	16	29	33	5	12	16–24	33	3
16	do	do	Bases soaked 48 hours	9(?)	21–24	33	10	24	29	33	5	24	29	33	2
11, 12	Feb. 15	do	Bases injected and soaked 19 hours.	9(?)	20–29	38	10	23	29	38	5	16	29	38	7
3	1926 Dec. 7	do	Bases on wet cotton	26	35	40	5	26	30	35	2	[b]	[b]	[b]	[b]
8	1927 Feb. 3	do	Injected and completely soaked 22 hours.	8(?)	14–22	24	2	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]

[a] No observation.

[b] No callus.

It is also apparent from Table 2 that preliminary water treatment tended to lower the temperature minimum and to extend the optimal temperature range. Although it can not be definitely stated from these preliminary data, it seems to be indicated that the temperature minimum and the optimal temperature range were somehow partially determined by the water relations, being also influenced, perhaps, by internal conditions that were innate in the cuttings themselves at the beginning of a test, conditions connoted by the vague expression "maturity of tissues." The relative intensity of rooting, mentioned just above, seems to have been influenced by maturity. The optimum temperature for rooting can not be fixed from the data at hand, though it is probably safe to guess that it lay generally in the vicinity of 26° to 28° C., except in some cases where special treatment had been applied to the cuttings. With the exception of excessively wet cuttings and those in experiments 5 and 6, which were subjected to low concentrations of oxygen, it seems that the maximum temperature was about 39°, and this did not appear to alter with maturity or with the season of the year.

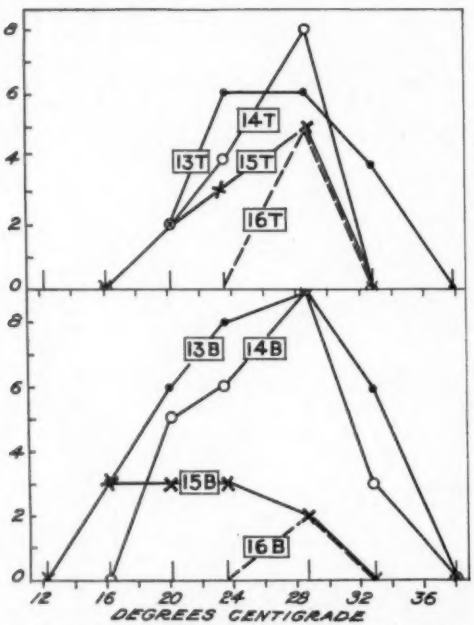


FIGURE 9.—Top-callus formation (13T, 14T, 15T, and 16T) and base-callus formation (13B, 14B, 15B, and 16B) of apple cuttings in closed chambers with flowing air and with different water treatments: Experiment 13, no water treatment; experiment 14, material completely soaked 1 hour; experiment 15, bases soaked 24 hours; experiment 16, bases soaked 48 hours

Independently of any effect brought about by water content, experiments 5 and 6 show that low supplies of oxygen may change the curve of rooting at optimal and supra-optimal temperatures without materially affecting the curve at sub-optimal temperatures. Further effects of low supplies of oxygen, especially at the higher temperatures, were apparent in experiments 8, 10, 15, and 16, where probably a considerable part of the residual air of the cuttings had been replaced by water. In such cases it seems that the oxygen supply and the temperature were very closely related; the higher the temperature the greater the supply of oxygen required for optimum growth.

As is shown by the graphs, in none of the experiments in which gas was flowing through the chambers did it seem to be indicated that large amounts or high pressures of oxygen had exerted any retardation upon the rooting of the apple cuttings. On the other

hand, the use of flowing oxygen did not seem to show any particular advantage over flowing air in the rooting of these cuttings. Thus from these experiments the use of partial pressures of oxygen higher than that in air with a total pressure of 1 atmosphere does not seem to be desirable.

CALLUSING OF APPLE CUTTINGS

In spite of the conclusion that callusing is not as important in the rooting of cuttings as it is commonly considered, studies regarding callus formation are likely to prove of importance, especially for such light as they may shed upon the callusing of grafts. In practical horticulture, at least two very important desiderata are here suggested: (1) The production of sufficient callus to make a mechanically and physiologically satisfactory union, and, (2) the prevention of such callus overgrowths at the union as are frequently confused with the galls brought about by the crown-gall organism, *Bacterium tumefaciens* S. and T.

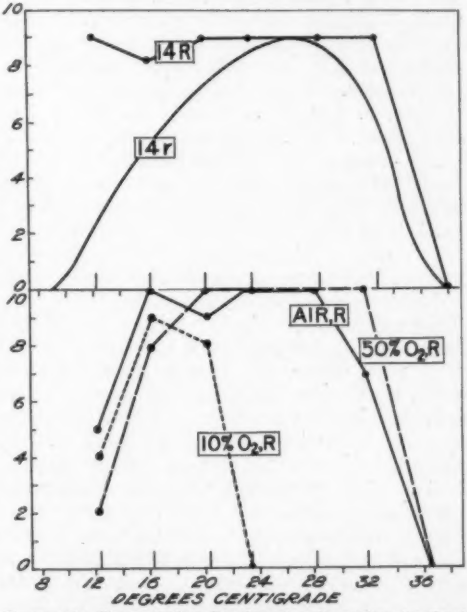


FIGURE 10.—Upper portion: Rooting of apple cuttings in closed chambers with flowing air, the cuttings having been preliminarily soaked one hour; 14R, the numerical results of experiment 14; 14r, estimated curve of actual rooting, based on experiment 14 and additional observations. Lower portion: Rooting of apple cuttings in sealed chambers filled with air, equal parts oxygen and nitrogen, or with 10 per cent oxygen in nitrogen, at the start of the test, no more interchange of gas taking place

Records of callus formation were not made for the intermediate temperatures of experiments 1 and 2. In experiment 3 (Table 1), with flowing air and bases of cuttings on wet cotton, there was practically no callus formation either at bases or tops, and the very slight callusing observed occurred at the tops of 3 of the 10 cuttings with maintained temperature of 30.3° C. In experiment 4, however (Table 1), which was like experiment 3 except that wire stilts were used instead of wet cotton, there was pronounced callusing at intermediate temperatures, and the graph of callus formation in this series (fig. 2, 4BT) has the form of growth-temperature curves in general. No differences between top callus and base callus were observed in this case, although such differences were shown for all the subsequent experiments with apple cuttings, as will be seen from the tabulated data. The graph indicates an optimum temperature of about 26° C. and minimum and maximum temperatures of about 18° and 40°, respectively. On comparing this callus graph with the corresponding graph for rooting (fig. 2, 4R), it is seen that the two are

very similar in form as well as in height, although it appears that the optimum temperature was somewhat higher for rooting than for callusing; but the rooting optimum shown for this experiment is unusually high for such optima.

That callus was plentifully formed at the intermediate temperatures in experiment 4 but was practically inhibited at all temperatures in experiment 3 suggests that this apparent inhibition may have been due to excess of water about the cutting bases in the latter case. An extra experiment was carried out with but a single temperature (27° C.), which showed that callus formation might be secured in spite of the presence of wet cotton about the bases of the cuttings. In this case there were four treatments, all with wet cotton at the bases but differing with respect to the rate of air movement through the bottles. The most rapid air flow was like that of experiment 3 (300 c. c. per hour), and the other rates were progressively lower (50, 20, and 10 c. c. per hour, respectively).

As in experiment 3, no base callus was observed with any of these four treatments, and top callus was extremely meager and practically negligible for the higher rates of air flow. However, it seems significant that the two tests with slowest air flow (20 and 10 c. c. per hour) showed top callus unquestionably more in evidence than it was in the cases where air flow was more rapid. Seven out of 10 cuttings showed small amounts of top callus in each of these cases. This extra experiment suggests that the retardation of top callus indicated by the results of experiment 3 might be offset to some extent with slower air change than was employed in experiment 3. Such a relation between callusing and rate of air flow might conceivably be due to differences in the evaporating power of the air corresponding to the different rates of flow, but this seems unlikely, since the air was practically saturated with water vapor in all these tests. It is suggested that the differences in top-callus formation here in question may have been due to differences in the oxygen supply corresponding to the differences in rate of flow. According to such a supposition, in support of which additional evidence will be given below, the extreme retardation in top-callus formation shown by the results of experiment 3 and by those of these two special tests with relatively high rates of air flow, may be regarded as due to too-rapid supply of oxygen. When air was supplied at a very slow rate (20 or 10 c. c. per hour), top callus developed much better than when the rate was more rapid (50 or 300 c. c. per hour). Other a priori considerations would require attention, however, if the interesting question thus raised were to be seriously studied. For an example of such considerations, products given off by the cuttings or by microorganisms might be more rapidly removed from the bottles with more rapid air renewal than from those with slower flow.

Perhaps the following statement may express the indications from experiments 3 and 4 and from the extra series: It appears that an excess of water about the bases of the cuttings inhibited callus formation at the bases and greatly retarded it at the tops, even for maintained temperatures in the optimal range, but that this retardation tended to disappear when the oxygen supply was much lower than in experiment 3.

In experiments 5 and 6 (Table 1) callusing was very active at both base and top for intermediate temperatures. It was about 33 per

cent less active at top than at base in the optimal temperature range. Graphs for the callus values from these two experiments are shown in Figure 4. In these cases the flowing gas was a mixture of oxygen (5 per cent) and nitrogen (95 per cent), and the rate of flow was more rapid (300 c. c. per hour) in experiment 5 than in experiment 6 (50 c. c. per hour). The minimum and maximum temperatures appear to have been about 13° and 38° for top callus, and the optimum with the slower flow of gas is indicated as about 28° for both base and top. In their optimal ranges the graphs for rapid gas flow are much flatter across the top than are the graphs for slow flow. Of the two rates of oxygen supply here tested, the more rapid rate produced more callus for sub-optimal and supra-optimal temperatures than did the slower rate, and it is therefore possible that a still more rapid rate of flow might have given an optimal range extending somewhat farther to the right, since the optimum rate of oxygen supply should be greater for the upper portion of the temperature range dealt with than for the lower portion. It is remarkable that a definite temperature optimum is not shown by either graph of experiment 5, although optima (about 28°) are clearly indicated by both graphs of experiment 6. From the results for 32.8°, it seems as if callusing at both top and base may be retarded by insufficient oxygen supply.

A comparison of callusing with rooting in experiments 5 and 6 indicates that the optimum and maximum temperatures were lower for rooting than for callusing. It is suggested that the minimum rate of oxygen supply necessary for rooting is significantly higher than the corresponding minimum rate for callusing.

Experiment 7 (fig. 5) with flowing oxygen gave more base callus than top callus, but callus formation was markedly retarded at all temperatures tested, as compared with the results of experiments 4, 5, and 6. From experiment 7 the highest score value for callusing is 3 (temperature about 30°) while the corresponding best callus score for experiment 4 is 5 (temperature about 26°) and for both experiments 5 and 6 it is 9 (temperature about 23° to 29°). A reason for this may be that in experiment 7 the oxygen supply was too great for excellent callusing at any temperature employed. It seems to be significant that the high oxygen supply of this test gave less callusing about the optimum temperature than was shown in any of the other experiments. It appears as though, for optimal temperatures and adequate moisture conditions, callus formation may differ from rooting by not requiring so much oxygen, and also by requiring an actually lower supply of oxygen. In other words, the lower limit of the range of oxygen supply that permits best growth may be lower for callusing than for rooting, and the extent of this range (from its lower to its upper limit) may be shorter for callusing than for rooting.

Experiments 8 and 9 in which flowing air was used were alike except for preliminary water treatment. The cuttings of experiment 8 had been injected with water and then completely submerged for 22 hours, whereas those of experiment 9 had not been injected, and only their bases had been submerged for the 22-hour period. No callusing was observed in experiment 8, but good callus formation occurred at the optimal temperatures in experiment 9 (fig. 6), which gave a maximum callus score of 6 (temperature about 29°.) From these two comparative tests it appears that excessive preliminary water treatment greatly retarded rooting and completely inhibited callusing.

The graph of callusing for experiment 9 (fig. 6) is in general typical, showing a marked tendency for base callus to surpass top callus. The minimum temperature is shown as somewhat lower for base callus (about 14°) than for top callus (about 18°), the maximum temperature is the same for both base and top callus (about 39°), and the optimal region extends from about 25° to about 30°. The treatment of experiment 9 seems to have been very good for both rooting and callusing, but not so good for callusing as were the treatments of experiments 5 and 6.

Experiments 10, 11, and 12, the last two being duplicates and all three having flowing air, constitute another test of the influence of preliminary water treatment along the subsequent gas treatment of flowing air. The cuttings of experiment 10 had their bases soaked 19 hours, while those of experiments 11 and 12 had their bases first injected with water and then soaked 19 hours. The graphs of these data are shown in Figure 7. It is not clear that any significant difference was brought out. As in the case of rooting in the same experiments, both treatments appear to have been good. The usual difference between top and base callus is brought out for both of these water treatments, and the temperature optimum for callusing is shown as about 29° for both treatments.

Experiments 13, 14, 15, and 16 were planned to obtain further evidence on the effect of preliminary water treatment on callusing as well as on rooting. The data for callus formation are presented graphically in Figure 9, and may be compared with those for rooting shown in Figure 8. The four treatments, all with flowing air, were as follows: Without preliminary water treatment (experiment 13); cuttings completely submerged in water for 1 hour (experiment 14); bases soaked in water for 24 hours (experiment 15); bases soaked in water for 48 hours (experiment 16). Although the evidence is not as clear as it might have been had this series been repeated several times so that averages could be secured, yet a study of Figure 9 indicates that in general both base and top callus were markedly decreased by soaking and that the retarding effect upon callusing seemed to be at least roughly proportional to the amount of soaking.

Excessive preliminary water treatment is again shown to diminish callus formation at each temperature within the total temperature range, without shifting of the optimum temperature. For rooting (fig. 8) the treatment of experiment 14 was clearly better than that of experiment 13, the standard treatment. The same difference was noted for callusing, but in the opposite direction. It seems to be indicated that while certain preliminary water treatments were beneficial for rooting, callusing was retarded, even by comparatively moderate water treatments, and this is spite of the indications already referred to showing that low oxygen supply (quite obviously associated with high water supply) favors callusing.

The excessive preliminary water treatments tested (experiments 15 and 16) showed retardation with respect to both rooting and callusing, but this effect was much more pronounced in the case of callusing.

In these experiments, as is true in general, base callus tended to be somewhat more pronounced than top callus when both were vigorous. But experiments 15 and 16, with excessive preliminary water treatments and low values for callus throughout, showed top callus surpassing base callus for the maintained temperature about 29° C. It

seems that the extra and excessive water treatment of the bases in these two cases retarded callus formation at both top and base, but not so pronouncedly at top as at base, where the water was applied. Exactly in what way this water treatment acted to retard or inhibit callus formation can not be stated. There are some reasons for believing that the presumable excess of water supplied to the tissues did not operate merely to retard movement of oxygen. The prolonged soaking may have removed some materials from the basal tissues, or other things may have happened. Almost all the cuttings of experiment 3, which had their bases surrounded by water (wet cotton) throughout the entire experiment period, failed to produce any callus at either base or top. The base of each cutting was subjected to continuous soaking, more prolonged than in the case of experiments 15 and 16. On the whole, the retardation in callus production seemed to vary directly with the length of the soaking periods, as has been noted.

Summary of Results of Experiments 1 to 16

The main numerical results of callusing, especially with regard to the cardinal temperatures, are summarized in Table 2 along with the corresponding data for rooting. The minimum temperature for callusing was several degrees higher than the minimum for rooting. In the case of rooting some activity was observed at the lowest temperature in every experiment started after the middle of January, but in the case of top and base callusing the cuttings used in the 16 experiments gave no evidence of activity at the lowest temperatures.

The minimum temperature for base-callus formation was not far from 16° C.; no callus was observed on cuttings when any temperature below 16.2° was used, and the amount of callus that occurred at any temperature below 20° had in no case an index value higher than 3.

In most of the experiments the optimum for base-callus formation was 29° C. The corresponding optimum for rooting lay between 26° and 28°; hence the optimum for base callusing was slightly higher than that for rooting.

Except in experiments 3, 8, 15, and 16, in each of which the cuttings had been given some excessive water treatment, the maximum temperature for base callusing was about 38° C. The maximum temperature was about the same for base callusing and rooting. Experiments 5 and 6 are exceptions to this, however, for in these cases the maximum temperature for rooting was lowered to about 34°, but no such effect was evident in the case of callusing. These exceptions are probably due to the low oxygen supply in these two experiments. The minimum oxygen supply was higher for rooting than for callusing.

In general, base callusing was more pronounced than top callusing, and this seems in some measure to have been responsible for the narrower temperature range indicated for top callusing. When nontemperature conditions are considered as not limiting, the apparent range for top callus is about 20° to 38° C., whereas that for base callus is about 16° to 38°. Whether the upper limit of these two apparent ranges (38°) is really the upper limit of the absolute range

for each process can not be definitely stated, but it seems likely that 38° is approximately the highest temperature at which any callus formation at either end of the cutting would occur, no matter what length of period was employed.

Apparently, no top callusing took place at any temperature below 20.3° C., and the most that occurred at any temperature below 23° is represented by an index value of 4 (experiment 4); thus the minimum temperature for formation of top callus was not far from 20° in these experiments. On the other hand, the minimum for the formation of base callus was about 16°.

The absence of callus on the cuttings of experiment 3 and on those at some of the maintained temperatures of experiments 15 and 16 does not imply that base callus can not ultimately develop when the cutting bases are water-logged, for considerable base callus was observed to have formed under water in some long-time experiments not here reported.

The studies of Knight (*9*) indicate that callusing was actually favored by water in his tests, for he observed more callusing in wet clay soils than in drier sandy soils. Knight's observations extended over several months rather than a few days, and in these experiments also the time factor seems to have played an important rôle. The observations of Knight seem to be in agreement with those of the present writer, if the suggestions be accepted that callusing is greatly retarded, but not inhibited by excessive amounts of water, and that the most important part played by sand in retarding callusing comes from its obviously very much higher oxygen supply.

Some evidence was secured indicating a seasonal relation of callusing similar to that shown for rooting (fig. 3) although this relation was not seriously studied for either callusing or rooting. For like treatments, experiment 13 (begun February 26) gave generally higher callus values than did experiment 4 (begun December 7). It appears that both rooting and callusing are more vigorous in the spring than in the fall, other conditions being similar and favorable, and of course the same is known to be true for the pushing of buds in such forms as apple.

No effect of buds upon the rooting or callusing of cuttings was observed. It appeared that rooting was confined entirely to the primordia visible on the cutting at the time it was taken from the tree, and that most of these primordia rooted, irrespective of the presence or absence of buds on the cutting. In almost all the tests callusing appeared to be closely associated with rooting, with certain environmental differences indicated, however, for optimal rooting and optimal callusing. A slightly higher temperature, a somewhat lower water supply, and a somewhat lower oxygen supply seemed to be required for optimal callus formation than for optimal root formation.

ADDITIONAL EXPERIMENTS ON ROOTING AND CALLUSING OF APPLE CUTTINGS

Several additional experiments with apple cuttings were performed, in some of which gas did not flow continuously through the experiment chambers. In these tests, chambers of different sizes or gas mixtures with different percentages of oxygen were used, the number of cuttings being the same in the different chambers of any series. In other cases flowing air was used, or the air of the chamber was renewed from time to time. In some experiments several different maintained temper-

atures were employed, and in others the temperature was the same for all chambers. Several different water treatments were used.

Three of these additional experiments (Nos. 17, 18, and 19) were performed with temperature series similar to those used in experiments 1 to 16. For these experiments, sealed chambers of about 1,000 c. c. capacity were used. The chambers were filled with a known gas mixture when the cuttings were inserted, and there was no gas flow. For experiment 17 the gas mixture was half oxygen and half nitrogen, for experiment 18 it was ordinary air, and for experiment 19 it was 90 per cent nitrogen and 10 per cent oxygen. All cuttings were soaked for one hour before they were placed in chambers.

The numerical data from these three experiments are presented in Table 3 and are graphically shown in the lower part of Figure 10. These results seem to emphasize further the suggestion obtained from the experiments with flowing gases: namely, that the oxygen supply requisite for optimum rooting or callusing is different for different temperatures. With the lowest oxygen supply (the 10 per cent mixture) the maximum temperature was about 23° C., but for the other two gas treatments (21 per cent and 50 per cent oxygen) the maximum was about 37°. For the lowest supply of oxygen, the optimum was about 17°, and for the two other gas treatments a broad optimal range of temperatures is evident, extending as far as 32° for the 50 per cent mixture.

TABLE 3.—*Numerical values for pushing of roots and growth of callus of apple cuttings in sealed chambers, without flowing gas*

Experiment No.	Conditions	Temperature	Roots	Callus			Temperature	Roots	Callus			emperature	Roots	Callus		
				Top	Base	Lenticel			Top	Base	Lenticel			Top	Base	Lenticel
		°C.					°C.					°C.				
17	50 per cent O_2	12.4	2	0	0	3	16.3	8	0	0	5	20.4	10	0	2	8
18	Air	12.4	5	0	0	3	16.3	10	0	2	5	20.4	9	0	2	7
19	10 per cent O_2	12.4	4	0	0	3	16.3	9	0	3	5	20.4	8	2	3	5

Experiment No.	Conditions	Temperature	Roots	Callus			Temperature	Roots	Callus			Temperature	Roots	Callus			Temperature of highest chamber (no growth)
				Top	Base	Lenticel			Top	Base	Lenticel			Top	Base	Lenticel	
		°C.					°C.					°C.					°C.
17	50 per cent O_2	23.5	10	0	3	9	28.3	10	0	3	9	31.9	10	0	0	9	36.7
18	Air	23.5	10	2	4	9	28.3	10	2	6	9	31.9	7	0	0	4	36.7
19	10 per cent O_2	23.5	0	0	0	2	28.3	0	0	0	2	31.9	0	0	0	2	36.7

Four additional experiments (Nos. 20, 21, 22, and 23) involved several different water and gas treatments, all carried out in the dark room at a temperature of about 19° C. All of these experiments began February 5, 1927, and for each one 23 cuttings were used. The several treatments and the rooting score values are shown in Table 4. It seems to be clearly indicated here, as in the results of experiments 3 and 8, that any considerable amount of wetting was detrimental to root pushing.

TABLE 4.—*Effect of water treatment on pushing of apple roots at about 19° C*

[Started on February 5; each test contained 23 cuttings]

Experiment No.	Preliminary treatment	Gas treatment	Roots (scale of 10)
20	None	Flowing, saturated air	9
21	do	Moist, open air; bases occasionally wetted	8
22	Soaked 24 hours	Flowing, saturated air	1
23	None	Nearly saturated air, changed daily; cuttings immersed 10 minutes daily.	.5

Two other experiments (Nos. 24 and 25) were also conducted in the dark room at a temperature of about 19° C., beginning March 4, 1927. Sealed chambers of different sizes were used, without any change of gas during the experiment period. In experiment 24 the chambers were originally filled with air, and in experiment 25, with oxygen. Twenty-five cuttings were used for each chamber, their bases having been soaked 24 hours before the test started. Each experiment gave comparisons between five different sizes of chambers. The volumes of the chambers and the score values for root pushing and for the production of top, base, and lenticel callus, as secured at the end of the 10-day period, are given in Table 5.

TABLE 5.—*Numerical values for pushing of roots and for growth of callus in apple cuttings in sealed chambers, with different gas mixtures, at a temperature of about 19° C.*

[Started on March 4; the bases of all cuttings were soaked 24 hours]

Experiment No.	Gas used	Volume of sealed chamber	Roots	Callus		
				Top	Base	Lenticels
		C. c.				
24–A	Air	5,400	10	0	3	8
24–B	do	3,000	10	0	3	8
24–C	do	2,700	10	0	2	6
24–D	do	1,800	7	0	1	4
24–E	do	1,000	1	0	0	2
25–A	Oxygen	5,400	10	0	0	7
25–B	do	3,000	9	0	0	6
25–C	do	2,700	9	0	0	5
25–D	do	1,800	10	0	0	3
25–E	do	1,000	3	0	0	2

In addition to offering indications as to the supply of oxygen necessary for optimum root pushing, these data show (1) that more base callus than top callus was formed and (2) that large supplies of oxygen had retarded callus formation at both ends of the cutting.

In experiment 26 (started October 18) the chambers used were large-mouthed bottles. The air in one bottle was swept out by oxygen, and a rubber bag containing oxygen under slightly more than atmospheric pressure was then connected and allowed to remain throughout the test; a second bottle was arranged in the same way, but oxygen was passed through it for a short period every day; the third bottle was filled with air at the start and was left with two small openings through which some gas exchange with the external air might occur. All cuttings rested with their bases upon damp cotton, and all bottles stood on a bench in the greenhouse without intense

sunlight. After three weeks all visible primordia had pushed except those in the sealed bottle with oxygen; here only a trace of activity was observed. It seemed quite evident that lack of oxygen rather than surplus of oxygen was responsible for this marked inhibition of rooting.

In two preliminary experiments the apple cuttings in some chambers were subjected to carbon dioxide (from a commercial tank) with nearly an atmosphere of pressure, while in other chambers the cuttings were subjected to nearly pure nitrogen. Both of these treatments showed injury as indicated by tissue disintegration in the bark and wood, but the cuttings treated with carbon dioxide were much more seriously injured than the others. In both cases injury was especially pronounced and rapid in the series of cuttings which bore leaves. Here, as in those without leaves, injury was evident sooner with carbon dioxide than with nitrogen.

The results of these additional experiments seemed to support the general conclusions reached in the main series, namely, that apple cuttings have a higher oxygen requirement for rooting than for callusing, and that any study of the oxygen supply required for rooting or callusing must include special consideration of the temperature. The experiments without flowing gas are to be considered as only superficial in their indications, because of the fact that the nature of the gas mixture undoubtedly changed during the experiment period and in an unknown manner. The oxygen content must have been decreased more or less rapidly through the respiration of the cuttings themselves and perhaps to a considerable degree by the oxidation occurring on the iron wire used as supports.

EXPERIMENTS WITH WILLOW CUTTINGS

The studies on willow cuttings were about equally divided between experiments with flowing gases and experiments with sealed chambers. The experiments with flowing gases will be considered first. Willow cuttings were present in the chambers of the first 12 experiments with apple cuttings.

The numerical results of these 12 experiments on willow are presented in Table 6. In addition to the numerical scores for rooting, derived as has been described for the experiments with apple cuttings, the results for willow include another value representing rooting activity, namely, the average number of roots per cutting evident at the end of the experiment. These additional values are given in the table in parentheses following the regular score values. Thus for experiment 5, for temperatures 20.6°, 23.6°, 28.6°, and 32.8° C., the root scores are, respectively, 1, 4, 5, and 5, and the new root values (in parentheses) are 0.3, 1.1, 1.7, and 1.0. In the third case, for instance, the score 5 indicates that half of the cuttings showed some root pushing, and the value 1.7 is the quotient obtained by dividing the total number of roots observed by the number of cuttings used.

Table 7 gives the numerical results of an experiment run at the same time as experiment 3. Here, however, only one temperature was used, and different rates of air supply were compared. These results will be considered only as regards callus formation, for rooting was similar in this case to that in experiment 3.

TABLE 6.—*Numerical values for pushing of roots and for growth of callus of willow cuttings*

Experiment No.	Date started	Conditions	Temperature	Pushing of roots [a]	Callus [b]			Temperature	Roots [a]	Callus [b]			Temperature	Roots [a]	Callus [b]			Temperature	Roots [a]	Callus [b]			Temperature	Roots [a]	Callus [b]			Temperature	Roots [a]	Callus [b]			Temperature of highest chamber; no growth
					Top	Base	Lenticel			Top	Base	Lenticel			Top	Base	Lenticel			Top	Base	Lenticel			Top	Base	Lenticel			Top	Base	Lenticel	
	1925		°C.					°C.					°C.					°C.					°C.					°C.				°C.
1	Nov. 8	Flowing O_2; bases on damp cotton	7.7	0	0	0	0	14.7	0	0	0	0	20.7	4 (*)	(*)		8	27.7	9	(*)	(*)		8	34.1	5	(*)	(*)	3	39.8	0	0	0	0	46.5
2	Nov. 23	Flowing air; bases on damp cotton	13.2	0	0	0	0	17.2	0	0	0	1	21.9	5	0	1	4	25.7	7	1	2		5	31.3	1	8	9	0	36.0	1	0	0	5	40.7
3	Dec. 7	Flowing air; bases on wet cotton	14.1	0	0	0	2	17.8	0	0	0	4	22.1	10	0	0	6	25.5	10	0	0		8	30.3	10	1	0	8	35.3	10	0	0	6	40.2
4	...do.....	Flowing air; bases on wire stilts	14.1	0	0	0	1	17.8	0	1	0	4	22.1	6	5	5	6	25.5	10	5	5		6	30.3	8	5	3	5	35.3	1	2	3	2	40.2
5	Jan. 5	Flowing 5 per cent O_2, fast; stilts	13.3	0	0	0	1	16.7	0	0	0	1	20.6	1 (0.3)	0	0	2	23.6	4 (1.1)	3	5		3	28.6	5 (1.7)	6	6	4	32.8	5 (1.0)	5	5	4	37.9
6	...do.....	Flowing 5 per cent O_2, slow; stilts	13.3	0	0	0	1	16.7	0	0	0	2	20.6	2 (0.7)	0	2	6	23.6	7 (2.5)	5	5		8	28.6	5 (2.1)	5	5	8	32.8	9 (3.0)	5	5	8	37.9
7	Jan. 21	Flowing O_2; stilts	14.4	0	0	0	1	17.9	0	0	0	2	21.7	0 (0.3)	1	2	3	24.8	3 (0.8)	2	3		3	29.7	3 (1.2)	1	0	3	33.8	1 (0.2)	0	0	1	38.9
8	Feb. 3	Flowing air; stilts; injected 22 hours	14.2	0	0	0	5	17.7	8 (3.0)	0	0	6	21.4	10(10.0)	0	5	7	24.5	10(15.7)	3	5		8	29.6	10(18.4)	2	5	8	33.7	10 (9.5)	0	3	7	39.0
9	...do.....	Flowing air; stilts; bases soaked 22 hours	14.2	0	0	0	4	17.7	6 (1.5)	0	2	5	21.4	9 (5.2)	0	4	7	24.5	10(12.1)	4	7		7	29.6	10(12.3)	5	8	7	33.7	10(13.7)	0	2	7	39.0
10	Feb. 15	Flowing air; stilts; injected 15 hours	12.4	0	0	0	3	16.2	6 (1.7)	0	0	5	20.3	10(14.7)	0	0	(*)	23.4	10(14.7)	0	4	(*)	6	28.6	10(21.2)	0	6	(*)	6	32.8	10(18.0)	0	5	(*)	37.6
11	...do.....	Flowing air; dry 22 hours; injected 25 minutes	12.4	0	0	0	3	16.2	7 (2.3)	0	0	5	20.3	10(12.8)	0	0	(*)	23.4	9 (17.3)	0	4	(*)	6	28.6	10(19.7)	0	6	(*)	6	32.8	10(20.0)	0	5	(*)	37.6
12	...do.....	Flowing air; dry 22 hours; injected 25 minutes	12.4	0	0	0	3	16.2	6 (2.6)	0	0	5	20.3	10(16.3)	0	2	(*)	23.4	9 (9.6)	0	4	(*)	6	28.6	10(19.5)	0	6	(*)	6	32.8	6 (10.3)	0	5	(*)	37.6
		Average of 11 and 12	12.4	0	0	0	3	16.2	6.5(2.5)	0	0	5	20.3	10(14.6)	0	1	(*)	23.4	9 (13.5)	0	4	(*)	6	28.6	10(19.6)	0	6	(*)	6	32.8	8 (15.2)	0	5	(*)	37.6

[a] The figures in this column represent the proportion of cuttings that showed some pushing of roots at the end of 10 days, calculated on the basis of 10. The figures in parentheses show the average number of roots per cutting evident at the end of the 10-day period.

[b] The figures in these columns represent the total amount of callus shown by all the cuttings in each lot (not the number of cuttings that showed some callus), based on an arbitrary scale of 10.

[*] No observation.

TABLE 7.—*Numerical values for pushing of roots and growth of callus of willow cuttings with a maintained temperature of 27° C. and with different rates of flowing gas*

[Started on December 7, 1926; all cuttings with wet cotton around bases]

Experiment	Speed of air flow	Roots	Callus		
			Top	Base	Lenticel
A	300 c. c. per hour	10	0	0	7
B	50 c. c. per hour	10	2	0	7
C	20 c. c. per hour	10	0	0	7
D	10 c. c. per hour	9	6	1	7

Table 8 shows the data from all experimentation with the seven different maintained temperatures when flowing gases were not used; each chamber was filled with the gas indicated and then sealed. Experiment 7–A is so numbered because it was run at the same time as experiment 7. Experiments 13 to 16 were all started February 26, 1927.

TABLE 8.—*Numerical values for pushing of roots and for growth of callus of willow cuttings with maintained temperatures, without flowing gases*

Experiment No.	Gas at start	Date started	Treatment	Temperature	Roots	Callus		Temperature	Roots	Callus		Temperature	Roots	Callus	
						Top	Base			Top	Base			Top	Base
		1927		°C.				°C.				°C.			
7–A	Oxygen	Jan. 21	Stilts	14.4	0	0	0	17.9	1	0	0	21.7	4	0	0
13	Air	Feb. 26	do	12.2	0	5	5	16.2	1	8	8	20.3	2	10	10
14	do	do	do	12.2	0	0	0	16.2	1	6	0	20.3	1	9	0
15	do	do	do	12.2	0	0	0	16.2	1	0	0	20.3	1	3	3
16	do	do	do	12.2	0	0	0	16.2	1	2	2	20.3	4	3	3

Experiment No.	Gas at start	Date started	Treatment	Temperature	Roots	Callus		Temperature	Roots	Callus		Temperature	Roots	Callus		Temperature of highest chamber; no growth
						Top	Base			Top	Base			Top	Base	
		1927		°C.				°C.				°C.				°C.
7–A	Oxygen	Jan. 21	Stilts	24.8	3	1	3	29.7	5	2	2	33.8	0	0	0	38.9
13	Air	Feb. 26	do	23.7	3	10	10	28.7	2	8	9	32.8	1	5	5	38.0
14	do	do	do	23.7	2	10	2	28.7	2	8	0	32.8	1	5	0	38.0
15	do	do	do	23.7	3	3	4	28.7	1	3	4	32.8	0	0	0	38.0
16	do	do	do	23.7	4	3	4	28.7	1	6	4	32.8	1	3	4	38.0

Table 9 presents the numerical results of all experimentation with willow in which the single-chamber constant-temperature apparatus was used except those given in Table 7. In none of the experiments referred to in Table 9 was flowing gas used; sealed chambers were employed in all cases, though in 4 of the 39 tests gas was passed through the chamber twice daily. In each of these tests the experiment period was seven days.

TABLE 9.—*Numerical values for pushing of roots, for average number of roots per cutting, and for growth of callus of willow cuttings, with maintained temperatures and with different gas supplies*

[All cuttings were on wire stilts, 50 cuttings in each lot]

Experiment No.	Date started	Temperature	Preliminary treatment	Size of bottle	Gas treatment	Roots		Callus		
						Cuttings rooted	Average roots per cutting	Top	Base	Lenticel
	1927	° C.		C. c.						
17-A	Jan. 8	27	None	4,200	Air, closed	6	2.5	2	3	3
17-B	do	27	do	4,200	Air, changed twice daily	2	.7	5	6	4
17-C	do	27	do	4,200	O_2, closed	5	1.2	1	2	3
17-D	do	27	do	4,200	O_2, changed twice daily	3	.8	0	0	2
18-A	Jan. 15	27	do	4,200	5 per cent O_2, closed	0	.3	0	0	4
18-B	do	27	do	4,200	5 per cent O_2, changed twice daily.	2	.7	3	5	5
18-C	do	27	do	4,200	N_2, closed	0	.1	0	0	1
18-D	do	27	do	4,200	N_2, changed twice daily	0	.2	0	0	2
19-A	Jan. 22	27	do	4,200	Air, closed	8	5.5	5	6	7
19-B	do	27	do	4,200	29 per cent O_2, closed	7	3.7	5	6	7
19-C	do	27	do	4,200	38 per cent O_2, closed	8	3.7	5	6	7
19-D	do	27	do	4,200	12 per cent O_2, closed	1	.5	3	4	7
20-A	Jan. 29	26.5	do	4,200	Air, closed	8	3.7	5	6	7
20-B	do	26.5	do	4,200	21 per cent O_2, closed	9	3.3	5	6	7
20-C	do	26.5	do	4,200	17.5 per cent O_2, closed	3	1.0	4	5	7
20-D	do	26.5	do	4,200	14 per cent O_2, closed	1	.5	3	4	7
21-A	Feb. 5	29	do	4,200	Air, closed	7	4.9	5	6	7
21-B	do	29	do	4,200	50 per cent O_2, closed	7	4.4	5	6	7
21-C	do	29	do	4,200	75 per cent O_2, closed	8	6.9	4	5	7
22-A	Feb. 12	29	do	5,400	Air, closed	6	3.7	7	8	7
22-B	do	29	do	4,200	do	5	3.0	7	8	7
22-C	do	29	do	2,700	do	2	.5	6	7	7
22-D	do	29	do	2,200	do	3	.9	7	8	7
23-A	Feb. 19	29	Injected	5,400	do	10	11.6	0	3	7
23-B	do	29	do	4,200	do	10	7.4	0	2	7
23-C	do	29	do	2,700	do	1	.7	0	1	7
23-D	do	29	do	2,200	do	0	.5	0	0	7
24-A	Feb. 27	29	Dry two days.	4,200	do	6	3.0	5	6	7
24-B	do	29	do	4,200	50 per cent O_2, closed	8	6.6	5	7	7
24-C	do	29	do	4,200	75 per cent O_2, closed	8	7.8	5	7	7
24-D	do	29	do	4,200	O_2, closed	9	7.1	5	7	7
25-A	Mar. 6	32	None	4,200	Air, closed	5	2.9	9	10	7
25-B	do	32	do	4,200	50 per cent O_2, closed	8	6.7	9	10	7
25-C	do	32	do	4,200	75 per cent O_2, closed	8	6.0	9	10	7
25-D	do	32	do	4,200	O_2, closed	9	7.0	9	10	7
26-A	Mar. 13	34.5	do	4,200	Air, closed	1	.6	7	8	7
26-B	do	34.5	do	4,200	50 per cent O_2, closed	4	1.9	7	8	7
26-C	do	34.5	do	4,200	75 per cent O_2, closed	4	2.7	5	6	7
26-D	do	34.5	do	4,200	O_2, closed	4	2.5	5	6	7

As in the case of the apple data, the results with willow, especially those with maintained temperatures and flowing gases, will be discussed mainly with reference to the corresponding graphs, Figures 11 to 17. In those graphs (figs. 15, 16, and 17) in which broken lines are used to represent average number of roots per cutting, the number representing the greatest average amount of root growth observed in any of these 12 experiments (21.2) has been taken as equal to 10 on the scale.

ROOTING OF WILLOW CUTTINGS

In experiment 1 (fig. 11, 1R), in which flowing oxygen was used, the total temperature range employed was much wider than the range of rooting, so that of the experiments at the seven temperatures only three showed any growth. The graph shows an optimum at 27.7° C.,

but it may have been several degrees higher or lower. The maximum appears to have been about 39° or below, while the minimum temperature is indicated as above 15°, probably below 18°.

In experiment 2 (fig. 11, 2R) the conditions of the test were similar to those of experiment 1 in that the bases of the cuttings rested on damp cotton, but in this case flowing air was used. The graph for experiment 2 shows an optimum at about 26° C., but from the data the optimum might just as well have been 28°. The maximum was about 40° or below. The minimum was slightly higher than that shown by experiment 1, being above 17° or possibly above 19°.

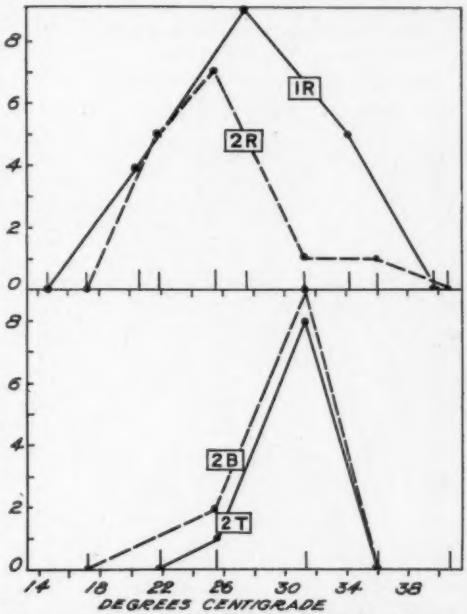


FIGURE 11.—Rooting (1R, 2R), top-callus formation (2T), and base-callus formation (2B) of willow cuttings in closed chambers with flowing oxygen (experiment 1) or with flowing air (experiment 2)

In experiment 3 (fig. 12, 3R) flowing air was used, and the bases of the cuttings, instead of resting on moist cotton, were surrounded to a height of about 5 cm. by wet cotton. This additional water seems to have produced a beneficial effect upon rooting, so that although maximum and minimum temperatures are indicated as before, no definite optimum temperature is apparent; the entire graph between the maximum and the minimum is thus raised to the top, for every cutting in each of the four chambers between 22.1° and 35.3° C. showed pushing of roots. However, notes on this experiment show that among the four temperatures more roots per cutting as well as longer roots were present at 30.3° than at 25.5°. With respect to these criteria, 22° seemed to be about equal to 35°, but with both the latter temperatures less rooting occurred than with 25.5°. Therefore, it seems that the additional water treatment of experiment 3 greatly increased rooting within the total temperature range, but did not appreciably alter the previously observed maximum, optimum, or minimum, here seen to be about 39°, 29°, and 18°, respectively.

Experiment 4 (fig. 12, 4R) was a duplicate of experiment 3, except that in experiment 4 the cuttings were supported on wire stilts so that no water came in contact with the cuttings. Again there is a temperature curve similar to the other curves discussed, with maximum and minimum not far from 40° and 18° C., respectively, and with an optimum indicated at 25.5°, but which may well have been

about 29°. While all cuttings did not root at 30.3°, this temperature was here, as in experiment 3, a slightly better one for the subsequent growth of the roots that did push than was 25.5°. Although the curve is for some unknown reason higher in experiment 4 than in experiment 2, still rooting in experiment 4 was much less than that observed in experiment 3, where the cuttings quite certainly were furnished with some water from the cotton. Apparently the beneficial effects of the water treatment were greatest at the supra-optimal temperatures rather than at the sub-optimal temperatures, as was observed in the corresponding experiment for apple rooting.

In experiments 5 and 6 (fig. 13) all cuttings were on wire stilts, and a flowing gas mixture containing 5 per cent oxygen was used. A rate of flow of about 300 c. c. per hour was employed in experiment 6, while a rate of about 50 c. c. per hour was used in experiment 5. In marked disagreement with the corresponding curve for apple rooting (fig. 3), the very low oxygen supply in experiment 6 at 33° C. appeared ample for good rooting in willow. In fact, except for the depression at 28°, the graph for experiment 6 is not unlike the other graphs for willow cuttings that were subjected to flowing gases without having been given some water treatment.

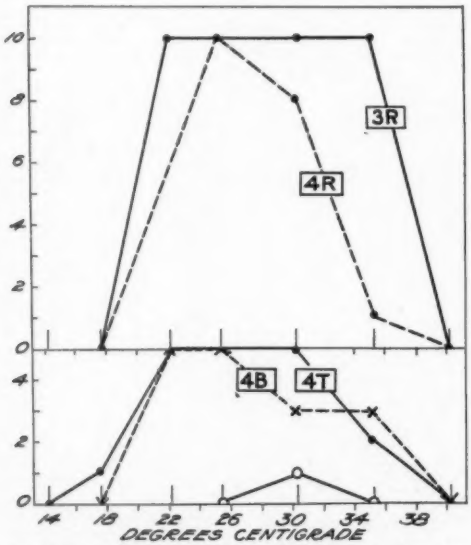


FIGURE 12.—Rooting (3R, 4R), top-callus formation (4T), and base-callus formation (4B) of willow cuttings in closed chambers with flowing air: Experiment 3, with the bases of the cuttings on wet cotton; experiment 4, with the bases on wire stilts. With the wetter conditions around the cuttings of experiment 3, only a trace of callus appeared

Another interesting point shown by Figure 13 is the fact that the graph for experiment 5 lies wholly below that for experiment 6. Supposing that the lots of cuttings for the different tests were similar, the most obvious differences between the conditions for experiments 5 and 6 are differences in amounts of water vapor and oxygen in the corresponding chambers, due to different rates of gas flow. It seems unlikely that there was any difference in the humidity of the gas about the cuttings in the two experiments. There was surely a much larger supply of oxygen in experiment 5 than in experiment 6, and it is possible that excess of oxygen may have slightly retarded rooting in the former experiments. There are, however, several possible objections to this suggestion; for example, the results of experiment 1 (with flowing oxygen) and of experiment 4 (with flowing air) appear to be in disagreement with it. It is possible that the presence of the wet cotton in experiment 1 may, in some

way, have counteracted unfavorable effects of high oxygen concentrations. This possibly injurious effect of large supplies of oxygen is also suggested in experiment 7 and in some of the experiments listed in Tables 8 and 9, in which continuously flowing gases were not used. On the basis of the supposition that large supplies of oxygen produce an injurious effect upon rooting of willow, it is hard to reconcile the results of experiment 4, where large quantities of air were passed through the chambers, where no liquid water was supplied the cuttings, and where, nevertheless, high percentages of rooting were secured.

In contrast to the corresponding results with apple, the willow cuttings in experiment 6 gave no evidence of oxygen deficiency at supra-optimal temperatures; the small amount of oxygen here supplied seemed to have been ample for good root growth, even at 32.8° C. Except with regard to the somewhat questionable optima, the graphs for experiments 5 and 6 agree with the other graphs for willow, showing maxima near 38° and minima at about 17°.

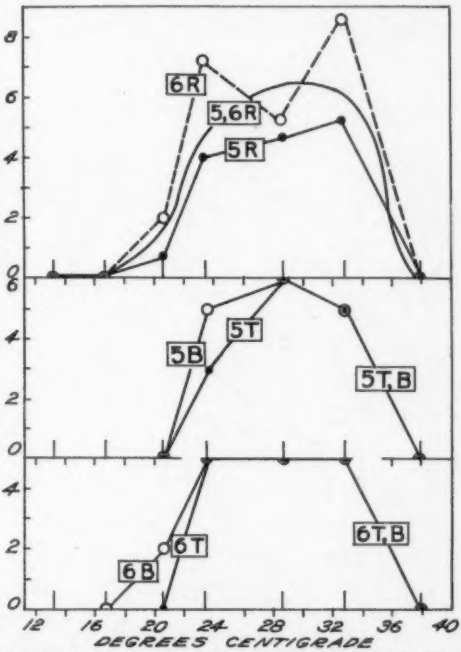


FIGURE 13.—Rooting (5R, 6R), top-callus formation (5T, 6T), and base-callus formation (5B, 6B) of willow cuttings in closed chambers with flowing 5 per cent oxygen in nitrogen

The results of experiment 7, as just mentioned, suggest that a large supply of oxygen may be detrimental to the rooting of willow cuttings. Although the usual maximum of about 38° C. is here indicated, experiment 7 (fig. 14, 7R) shows the only graph obtained in all these 12 experiments in which the minimum is above 18°; here the minimum is about 22°. The optimum (about 25°) is likewise unusual. All score values in this experiment are low, which seems to support the suggestion that an excess of oxygen may retard rooting in willow.

The striking differences brought out in Figure 14, between the results of experiment 1 (flowing oxygen, started November 8) and those of experiment 7 (flowing oxygen, started January 21) hardly seem to have been the result of seasonal differences in the capacity of the cuttings to produce roots. They seem rather to have been related either to unlike variability in the two lots of cuttings or to differences in water supply; the cuttings in experiment 1 may have

been supplied with sufficient water to counteract any injurious effect caused by surplus of oxygen.

In experiments 8 and 9 (fig. 15) the maxima and minima were similar to those shown by most of the other willow experiments (about 39° and 15° C., respectively). But in these two experiments, as in experiment 3, where also the cuttings had been treated with water, the optima are not clear, for all score values for temperatures below the maximum are 10 or only slightly below. Nevertheless, by considering the average number of roots per cutting the optima are seen to lie in the vicinity of 28°. (The broken lines—marked 8r and 9r in fig. 15, 10r in fig. 16, and 11, 12r in fig. 17—indicate the total average number of roots per cutting, the greatest number obtained in any of these experiments—21.2 per cutting in experiment 10—being taken as 10 on the scale of ordinates used.) In contrast to results obtained with apple cuttings, willow cuttings completely soaked for 22 hours after a 15-minute injection gave decidedly higher rooting values than cuttings that had the bases only soaked for 22 hours; the latter treatment, however, gave much higher values than no water treatment at all. In fact, these willow cuttings were benefited directly in proportion to the intensity and length of the water treatment used. The only reason for supposing that prolonged water treatments at high temperatures may have been injurious (as, for example, because of lack of oxygen) arises from the fact that a slightly greater number of roots per cutting were shown by experiment 9, as compared with the number in experiment 8, at the highest temperature at which rooting occurred (33.7°). Although this difference in number of roots per cutting (13.7–9.5) is not large, it is in the direction that might be expected from the results with apple; for it seems reasonable to suppose that rooting of willow may be retarded by lack of oxygen, even though the critical limit lies far below that for rooting of apple.

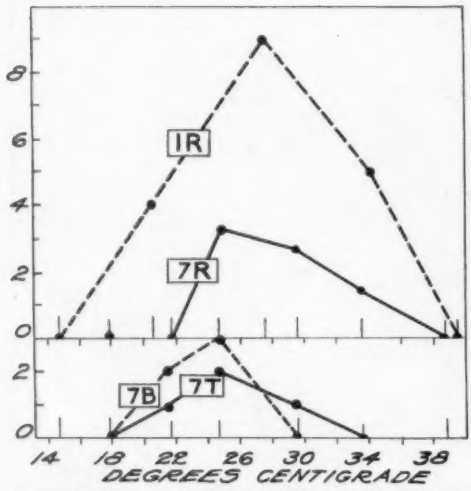


FIGURE 14.—Rooting (1R, 7R), top-callus formation (7T), and base-callus formation (7B) of willow cuttings in closed chambers with flowing oxygen. Experiment 1, bases on damp cotton; experiment 7, bases on wire stilts

The cuttings in experiments 10, 11, and 12 showed more rooting than those in the experiments with willow. Of these cuttings, those in experiment 10 (fig. 16) were given the longest water treatment and showed the greatest root growth. In experiments 11 and 12 (fig. 17) the cuttings were kept dry for one day and then given short, intensive

water treatment before being placed in the chambers; thus, whatever the total amount of water supplied to the cuttings by the two different treatments, at the end of the test the cuttings of experiment 10 had really been under rooting conditions for 10 days, as opposed to only 9 days for the others. Those used in experiments 11 and 12 received essentially identical treatments throughout, being run as duplicates in different chambers at the same temperatures.

With respect to maximum and optimum temperatures (about 37° and 29° C., respectively), the results of these three experiments (Nos. 10, 11, and 12) agree closely with those of most of the other willow tests. But these three experiments show lower minimum temperatures than any of the others with willow. A high-score value for rooting was obtained at 16.2°, and the minimum temperature for discernible root growth in 10 days lies not far from 13°.

Next to these low minima obtained in experiments 10, 11, and 12, started February 15, the lowest temperatures at which any rooting occurred were in experiments 8 and 9, started February 3; these experiments showed high-rooting values for 17.7° C. It is interesting to compare these results at a temperature of 17.7° in the two experiments last mentioned with the results at a similar temperature in experiment 3 (started December 7). The high-score values shown in both cases for other temperatures indicate that the water treatments used were satisfactory for good growth; but at a temperature of 17.8° in December no rooting whatever was evident, while at a temperature of 17.7° in February a large proportion of the cuttings rooted. As with the apple cuttings, it seems that some seasonal factor was involved which is evident in the graphs only in the vicinity of the minimum.

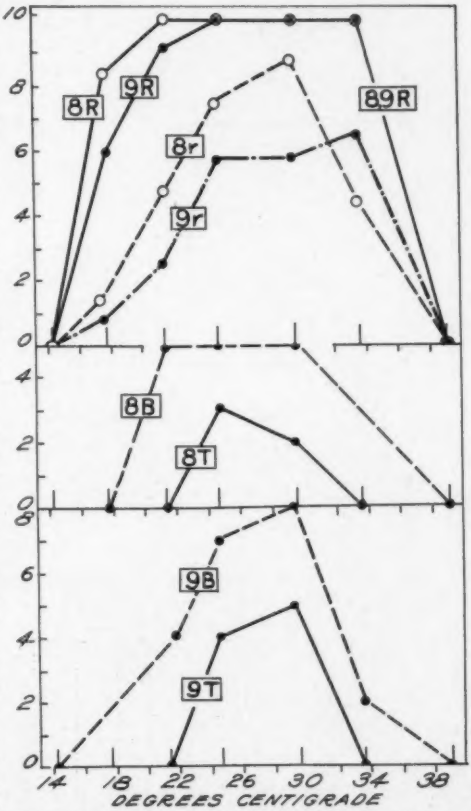


FIGURE 15.—Rooting (8R, 9R, 8r, 9r), top-callus formation (8T, 9T), and base-callus formation (8B, 9B) of willow cuttings in closed chamber with flowing air. Experiment 8, cuttings injected with water and completely immersed for 22 hours; experiment 9, bases of cuttings soaked for 22 hours

TABLE 10.—*Summary of results of experiments 1 to 12 in rooting and callusing of willow cuttings*

Experiment	Date started	Flowing gas	Water conditions	Data for rooting				Data for top callusing				Data for base callusing				Data for lenticel callusing			
				Approximate cardinal temperatures			Index for optimum temperature	Approximate cardinal temperatures			Index for optimum temperature	Approximate cardinal temperatures			Index for optimum temperature	Approximate cardinal temperatures			Index for optimum temperature
				Minimum	Optimum	Maximum		Minimum	Optimum	Maximum		Minimum	Optimum	Maximum		Minimum	Optimum	Maximum	
	1926			° C.	° C.	° C.		° C.	° C.	° C.		° C.	° C.	° C.		° C.	° C.	° C.	
1	Nov. 8	Water saturated O_2	Bases on damp cotton	17	27	40	9	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	10(?)	21–28	40	8
	1927																		
7	Jan. 21	do	Cuttings not in contact with water.	22	25	38	3	18	25	34	2	18	25	29	3	10(?)	22–30	38	3
5	Jan. 5	Water-saturated mixture, 5 per cent O_2, 95 per cent N_2.	do	17	33	38	5	21	29	38	6	21	29	38	6	10(?)	29–33	38	4
6	do	do	do	17	33	38	9	21	23–33	38	5	17	23–33	38	5	10(?)	24–33	38	8
	1926																		
4	Dec. 7	Water-saturated air	do	18	25	40	10	13	22–30	40	5	18	22–26	40	5	10(?)	22–25	40	6
2	Nov. 23	do	Bases on damp cotton	17	25	40	7	22	31	36	8	17	31	36	9	15	26	40	5
	1927																		
10	Feb. 15	do	Injected, completely soaked 15 hours.	13	20–33	38	10	(b)	(b)	(b)	------	20	29	38	6	(a)	(a)	(a)	------
9	Feb. 3	do	Bases soaked 22 hours	14	25–34	39	10	21	29	34	5	14	29	39	8	8(?)	22–34	39	7
11, 12	Feb. 15	do	Dry 22 hours, injected 25 minutes.	13	20–30	38	10	(b)	(b)	(a)	------	16	29	38	6	(a)	(a)	(a)	------
	1926																		
3	Dec. 7	do	Bases surrounded by wet cotton.	18	22–35	40	10	26	30	35	1	(a)	(a)	(a)	------	10(?)	25–30	40	8
	1927																		
8	Feb. 3	do	Injected, completely soaked 22 hours.	14	21–34	39	10	21	25	3	35	18	21–29	39	5	8(?)	24–30	39	8

[a] No observation.

[b] No callus.

Summary of Results of Experiments 1 to 12

The main numerical results of the experiments with willow cuttings in which flowing gases and maintained temperatures were used have been brought together in Table 10, as was done for the corresponding results with apple cuttings in Table 2.

The minimum temperature for rooting of willow apparently changed from about 18° C. early in the season to about 13° later in the season. On the other hand, the maximum temperature seems to have been at all times, whatever treatment was employed, about 38°, that is, about the same as that indicated for rooting and callusing of the apple. Except for the suggestion offered in experiments 8 and 9, apparently in none of these tests with willow did the supply of oxygen fall below the critical limit, even at the higher temperatures. Hence, from these particular experiments little is seen to indicate that the supply of oxygen necessary for rooting was in any way dependent upon the temperature. However, from the results obtained without flowing gases, which will be considered later, it appears that the failure of experiments 1 to 12 to show any definite effect of oxygen deficiency may be explained by supposing that the oxygen requirement for willow is very low and was satisfactorily met in all cases where flowing gases were used.

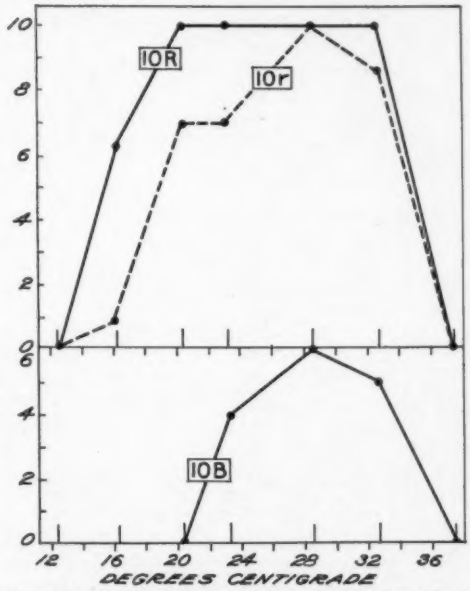


Figure 16.—Rooting (10R, 10r) and base-callus formation (10B) of willow cuttings in closed chambers with flowing air and with the cuttings injected with water and soaked for 15 hours at the start of the test. No top callus formed with this intensive water treatment

On the basis of the rooting scores the optimum temperature is not indicated so clearly as are the maximum and minimum, for at all temperatures between 20° and 33° C. rooting was very good; judged by the average number of roots per cutting, however, the optimum temperature was about 29°.

It should be emphasized that the minimum temperature for visible root growth in 10 days was several degrees higher for willow than for apple. Although much activity was observed in apple cuttings subjected to the lowest temperatures, in every series of willow cuttings the lowest temperature employed was too low for rooting.

On the other hand, apple and willow were approximately alike in respect to their optimum and maximum temperatures. Although in these 12 experiments with flowing gases there was no indication of oxygen deficiency, the results of experiment 7 (the only experiment with flowing oxygen in which water was not available to the cuttings) suggested that the use of oxygen with a pressure of about 1 atmosphere (an oxygen excess) may have been instrumental in raising the minimum temperature as well as in greatly decreasing the index values for all temperatures at which rooting occurred.

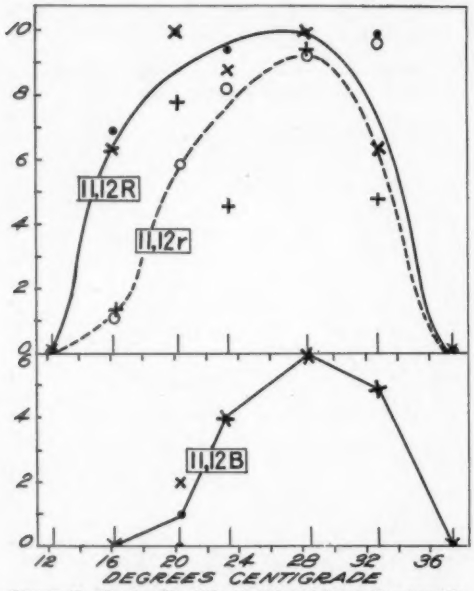


FIGURE 17.—Rooting (11, 12R; 11, 12r) and base-callus formation (11, 12B) of willow cuttings in closed chambers with flowing air, the cuttings having been injected with water after 22 hours of drying. No top callus formed with this treatment

In regard to water supply, the results indicate that the more intense or prolonged the water treatment the greater was the rooting response. In this respect willow cuttings were very different from apple; some water treatments were highly beneficial for the rooting of apple cuttings, but more prolonged treatments were injurious.

In the experiments with willow no evidence was secured in support of the supposition that the presence of buds exerts any direct influence, as through hormones, upon root pushing. Inasmuch as all of the willow cuttings bore buds, these experiments differed from those with apple cuttings in that they did not furnish any evidence against the supposition just mentioned.

CALLUSING OF WILLOW CUTTINGS

The numerical data for callusing in willow cuttings in the experiments with flowing gases are shown by graphs based on Table 6.

Except for temperature influence, no important differences in callus formation are evident in the series of gas and water treatments employed in these 12 experiments. A graph for base-callus formation with a minimum of about 18° C., an optimum of about 29°, and a maximum of about 38° answers well for all these tests except experiments 3 and 7.

In experiment 3 the only callus observed on either end was a trace of top callus produced at a temperature of 30.3° C. In itself, this almost total absence of callus on cuttings that showed a very large amount of rooting suggests again that roots and callus may reciprocate, the

activity being variously divided between rooting and callusing. However, a closer examination of the results with willow cuttings seems to indicate here, as with apple, that such reciprocation was not involved, but rather that there are actual differences between the requirements for rooting and for callusing. The bases of the cuttings in experiment 3 (being surrounded by wet cotton) were evidently too wet for callus formation, although such conditions were very good for root formation. The lack of top-callus formation in experiment 3 may, perhaps, have been due to excessive water treatment or to this water treatment in conjunction with the large oxygen supply. In the case of the special modification of experiment 3 in which different rates of air flow were employed at a single temperature (see Table 8), top callus was evident only with the lower rates of flow.

The score values for base callusing shown by experiment 7 are lower than the corresponding ones for any of the other experiments with flowing gases except experiment 3 and its modification. The extremely low maximum and optimum temperatures indicated by experiment 7, about 29° and 25° C., respectively, may have special significance, or they may show merely that all values were too low to give satisfactory temperature indications. These extremely low values for base callusing can not be explained either by a reciprocation of callusing with rooting or by excessive treatment with water. It seems that a surplus of oxygen was in some way responsible for them.

It may or it may not be significant that the only values higher than 6 for base callus were obtained in experiments 2 and 9 with cuttings that had been treated with water. While it may be that some treatment was beneficial to callusing of willow, it seems that even in willow cuttings any water treatment tended to retard callusing. This was especially evident in experiment 3 and in experiments 10, 11, and 12. In the last-mentioned experiments, although the index values for base callusing are about like those for the other experiments, top callusing was entirely inhibited by the injection treatment. In experiment 8, the other experiment in which the cuttings were injected under reduced pressure, only slight top callusing was evident; and in experiment 9, in which the cuttings were not injected but were soaked 22 hours, values for top-callus formation were more different from those for base callus than were the values shown by cuttings neither soaked nor injected. Thus in general, where the cuttings were given water treatment, the temperature range for formation of top callus lay well within the range for base callus, and in these cases the curves of minimum and maximum temperatures are not far from 21° and 34° C., respectively; also, the optima are uncertain, and all index values are low.

Except for the high value shown near 31° C. in experiment 2 and another near 29° in experiment 9, the conditions of these 12 experiments were not good for either base-callus or top-callus formation, whatever gas or water treatment was employed.

Lenticel Callus

Other workers have made many studies of the external conditions influencing tissue hypertrophy around lenticels (lenticel callus). These studies have clearly demonstrated the close relationship existing between oxygen deficiency and water surplus in bringing about

lenticel hypertrophy when the temperatures are adequate, but apparently no special study has been carried out with reference to the part played by these different factors.

Although the system of score values for lenticel-callus used in the present studies is not wholly satisfactory, some indications with regard to lenticel-callus formation may be added here.

Regarding the temperature curve for lenticel-callus formation, the data presented in Tables 6 and 10 indicate maxima about 39° and minima about 10° C. The optima are not so definite, for in general little difference was shown for any one series within the temperature range between 22° and 30°.

Although the gas and the water treatments employed in these experiments seem to have had little influence upon the cardinal temperatures, the index values obtained were markedly influenced by such treatments. Experiment 1 shows that at proper temperatures lenticel callus may form with a high partial pressure of oxygen surrounding the cuttings. Considering the low values of experiment 7 (flowing oxygen, bases of cuttings on stilts) in contrast with the high values of experiment 1 (flowing oxygen, damp cotton around bases of cuttings), the external supply of oxygen seems to have been of much less importance in lenticel-callus formation than was the water supply. This suggestion is supported by the difference in results shown between experiments 3 and 4 and between experiments 8 and 9. When experiments carried out at the same time are considered, lenticel callusing was increased in proportion to the quantity of water supplied to the cuttings.

However, considering the differences between experiments 5 and 6 (both without water treatment) lenticel-callus formation seems to have been favored by a low oxygen supply; in experiment 6, in which the cuttings received only 50 cubic centimeters per hour of a mixture of 5 per cent oxygen, index values were markedly higher than those of experiment 5, in which the same gas mixture was passed through the chambers approximately six times as fast.

Thus these willow cuttings subjected at adequate temperatures to negligible rates of evaporation showed formation of lenticel callus with any gas mixture tested, whether supplied with water or not; but such hypertrophy was accelerated either when the partial pressure of oxygen was low or when water was supplied to the cutting.

ADDITIONAL EXPERIMENTS ON ROOTING AND CALLUSING OF WILLOW CUTTINGS

Some additional experiments on rooting and callusing of willow cuttings were made, the numerical results of which are shown in Tables 8 and 9. Experiment 7–A (Table 8) was a duplicate of experiment 7 (Table 6) except that instead of having continuously flowing oxygen the chambers were swept out with oxygen at the start of the experiment, and this was repeated 12 hours later, after which the chambers remained sealed. Unlike experiment 7, this experiment shows about the usual minimum rooting temperature (15° C.) and the usual optimum (about 29°). But the maximum temperature (33.8°) is lower than that in any of the willow experiments with flowing gases. At this temperature actual injury was sustained because of oxygen deficiency. Although more oxygen was introduced into each chamber in experiment 7–A than was supplied in experiment 6 (slowly flowing 5 per cent oxygen), rusting of the wire stilts

took place rapidly, and the available supply probably fell below the critical limit for rooting. It is uncertain whether in experiment 7–A the generally low rooting values were all due to deficiency in oxygen, or whether under some temperature conditions an optimum supply was available. The occurrence of the generally low callus values here shown suggests that injury may possibly have occurred at the lower temperatures because of too much oxygen.

The four experiments, Nos. 13 to 16, were all run at the same time (February 26 to March 8); each chamber contained air when sealed, and (except in experiment 13) some preliminary water treatment had been given to the cuttings.

In experiment 13 the low values for rooting and the very high values for callusing are in accord with previous suggestions that callus formation is favored by a very low oxygen supply and that, although the required oxygen supply for rooting of willow is low, it is not nearly so low as is that for callusing in the same plant. In this experiment, at every temperature employed, except perhaps near the minimum, the supply of oxygen fell during the experiment period below that required for good root formation. At 28.7° and 32.8° C., temperatures which other experiments have indicated as being near the optimum for callusing, the oxygen supply fell even below the low amount required for optimum callus formation. Consequently, the temperatures here indicated for optimum callusing (20.3° to 23.7°) are much below the optimum (about 29°) indicated by experiments 1 to 12.

The results of experiment 13 show that, for the suboptimal temperatures employed, conditions were very good for callusing of willow; in fact, better than in any other of the writer's experiments. The fact that at a temperature of 12.2° C. moderate callus was here observed at both top and base indicates that the temperature minima (about 18° to 21°) shown by the experiments with flowing gases were too high. Apparently in every case in experiments 1 to 12 willow callusing was in general greatly reduced because of excess of oxygen.

Experiment 14 (in which the bases of the cuttings were soaked 24 hours) showed rooting values as low as or lower than those for experiment 13 at the corresponding temperatures, indicating for willow (as has already been observed for apple) that, with deficiency of oxygen, injury was even more pronounced with wet cuttings than with dry ones. In this case callusing at the bases of the cuttings (the region soaked for 24 hours) was almost negligible, while the values for top-callus formation are very high—almost as high as those for experiment 13. That the almost total absence of base callus was not entirely due to the 24-hour soaking seems indicated by the fairly high callusing values shown in experiment 9 (Table 6), where, with flowing air, cuttings whose bases had been soaked for 22 hours showed more callus formation at the base than at the top.

In experiment 15 (in which water was injected into the cuttings for 25 minutes) and experiment 16 (in which the cuttings were soaked one hour) the values for callusing are again low, and the values for rooting are even lower. The available oxygen supply here also probably fell much below the critical limit for optimum rooting and even somewhat below that required for optimum callusing. Injecting the cuttings seems to have decreased rooting and callusing slightly more than immersing them for one hour; in experiment 15 the maxi-

mum temperature for both rooting and callusing was below 33° C. It is probable that the lower callusing activity shown by these last three experiments was not entirely due to oxygen deficiency, for indications that treatment of the cuttings with water tends to retard callusing, irrespective of the effect of such treatment on oxygen supply, have already been referred to.

In Table 9 are shown the results of two experiments (Nos. 17 and 19) with gas not under continuous flow, which again indicate that a large supply of oxygen may retard rooting. In experiment 17 air and oxygen were used, with chambers A and C remaining closed throughout the 7-day period and with the gas bubbled through chambers B and D every 12 hours. The cuttings in chamber A (air closed) showed the highest rooting values of the four, those in chambers B (air, changed) and D (oxygen, changed) showing much lower rooting values. This experiment indicates that a large supply of oxygen was injurious, irrespective of the partial pressure employed. Experiment 19, A to D, also showed some indication that oxygen in excess may act injuriously upon the rooting of willow. Although the proportion of cuttings that rooted was not appreciably lower in chambers B and C than in chamber A, the lower average number of roots per cutting may have been due to higher oxygen content.

Table 9 also refers to many experiments with willow in which low rooting values seem clearly to have been due to deficiency of oxygen. In experiment 18, A to D, nitrogen, or a mixture of nitrogen and oxygen with 5 per cent of the latter, was used, no change of gas taking place in chambers A and C, but with the gas in chambers B and D changed every 12 hours. In all cases very low rooting values were obtained, but the highest value was for the chamber through which the largest amount of oxygen passed. In spite of the total amount of oxygen inserted in chamber B, it seems probable that, due to the rusting of the iron-wire stilts, an actual deficiency of oxygen occurred in this case as well as in the other three bottles where obviously very little oxygen was available for rooting.

In every experiment referred to in Table 9 (except experiment 17) one or more chambers showed evidence of oxygen deficiency. In some cases this deficiency was brought about by an insufficient volume of air, in some cases by inadequate partial pressure of oxygen in the gas mixture, and in some cases by a temperature too high for the other conditions.

The cuttings in experiment 23, chamber A, gave the highest rooting values obtained without flowing gases. The rooting values for the cuttings in chamber B and for those in chamber C are markedly different, which may well have been due to a difference in the available oxygen supply per cutting between the chamber that contained 4,200 c. c. of air at the beginning of the experiment and the chamber that contained 2,700 c. c.

The experimental results given in Table 9 appear to support the suggestion that callusing and rooting values do not reciprocate, but rather that each process is independent of the other, being influenced by water, oxygen, and temperature. Table 9 further indicates that callusing of willow was retarded (1) when water treatment was excessive (experiment 23), (2) when oxygen supply was too great (experiments 17 and 21), and (3) when oxygen supply was too small (experiments 18, 19, 20, and 23).

No clear indications regarding the controlling external factors for lenticel-callus formation were obtained in the experiments without flowing gases. Moderate lenticel callusing occurred whether the cuttings were supplied with large or with small amounts of water or oxygen. Only in experiment 18 (where all chambers had very little oxygen) did there appear any indication that oxygen supply was a limiting factor. Here all values for this form of activity were low, and apparently the lower the oxygen supply the lower were the values obtained. Also lenticel callusing seems to have had an even lower critical limit of oxygen supply than had top or base callusing.

A preliminary experiment set up October 26, 1926, indicated, however, that even with negligible amounts of oxygen very large lenticel calluses may form in time. In this experiment the bases of the cuttings rested on damp cotton, and nitrogen was bubbled through alkaline pyrogallol solution and then through the chamber containing the cuttings. A rubber bag with nitrogen under slightly more than atmospheric pressure remained attached to the chamber, the pyrogallol bottle being between the bag and the chamber. The set-up was placed in the greenhouse, shaded from intense sunlight. After one month the cuttings showed very large lenticel calluses, but rooting was almost negligible. Neither rooting nor callusing occurred during the next 12 days. On December 8 the chamber was opened to the air, and four days later many roots were visible on each cutting, indicating that lack of oxygen in the first part of the experiment had been the chief factor to retard rooting, even though optimum conditions had been offered for lenticel-callus formation.

Few indications regarding cardinal temperatures are to be obtained from Table 9, since only a single temperature was employed in each experiment. It may be noted, however, that the highest rooting values were shown by injected cuttings kept at 29° C., while the highest values for top and base callusing are shown by cuttings kept at 32° and supplied with additional water. In general, the higher the temperature the greater the supply of oxygen necessary for optimum rooting. This seems to have been indicated only slightly for callusing at top or base, and not at all for lenticel callusing.

In an experiment carried out in April, 1926, it was observed that one lot of willow cuttings with bases in water showed the same root development as did another lot with bases embedded in a 1.25 per cent agar gel. In the light of the more recent experiments, these results suggest that either the small amount of oxygen necessary for rooting was able to diffuse fast enough through the agar, or else the necessary oxygen reached the bases of the cuttings through the freely exposed tops. Tradescantia cuttings treated in the same manner as the willow cuttings also rooted in agar, but with this difference—the roots formed only near the top of the gel, suggesting that more oxygen is required for its rooting than for willow.

The experiments here reported with willow cuttings without flowing gases are no more than preliminary, but the results obtained seem to strengthen some of the suggestions brought out in experiments 1 to 12; namely, (1) that for both rooting and callusing a rather definite and comparatively low supply of oxygen is necessary; (2) that the minimum oxygen supply for callusing is less than that for rooting; (3) that excess of oxygen may slightly retard rooting and markedly retard callusing; and (4) that the oxygen minimum is

greatly dependent upon the temperature. The chief difference between apple and willow as shown in these experiments seems to lie in the much higher point for the oxygen minima in the former.

SUMMARY

The experiments here reported were of a general and exploratory nature, planned to secure indications as to promising methods of procedure in both the planning and the execution of tests of rooting and callusing. Fall, winter, and spring cuttings were tested in darkness, at seven different maintained temperatures in each of 16 series with constantly flowing gas, and these series differed with respect to the oxygen and water conditions in the test chambers. Some preliminary treatments with water were tested in this way, and some experiments were tried without flowing gas. With the different maintained temperatures and with flowing gas the experiment period was 10 days, while an experiment period of 7 days was used in some of the tests without flowing gas. The plants used were apple of the Springdale variety and willow (*Salix alba* L.), both of which have preformed, dormant root primordia under and in the bark. In the Springdale apple these primordia occur in groups, forming burrknots. The apple cuttings were made from wood from 3 to 10 years old; most of the willow cuttings were made from wood 2 years old.

Results with Apple Cuttings.—For the 10-day period the temperature curve of rooting showed generally a minimum of about 8° to 14° C., a maximum of about 39°, and an optimum of about 24° to 29°; but these cardinal points of the temperature relation were apparently shifted or modified according to the oxygen and water conditions.

The maximum temperature was consistently about 39° C. in all cases where the oxygen supply was adequate. When the oxygen supply was apparently inadequate, the maximum temperature was not so high.

The optimum temperature appeared to be influenced by internal conditions related to the seasonal maturity of the shoots from which the cuttings were made. With apparently adequate oxygen and water conditions the optimum for the spring cuttings seemed to be shifted downward on the temperature scale, and it was also markedly broadened into an optimal range. The fall cuttings showed a more definite and somewhat higher optimum than did the spring cuttings, and the latter rooted equally well throughout an extensive optimal range.

The numerical values or scores representing the amount of rooting were considerably greater for the optimal temperature range in the spring than they were for the fall optima. In the later tests, with more mature shoots, at sub-optimal and supra-optimal temperatures the rooting values were greater than at optimal temperatures in the fall tests. More rooting and rooting at lower temperatures generally occurred in cuttings made and tested in March than in those made and tested in November.

The minimum temperature for rooting appeared to be decidedly lower in the spring tests than in the fall tests, suggesting that the minimum was shifted downward on the temperature scale as the shoots became more mature.

The minimum temperature for rooting did not seem to be influenced by water and oxygen conditions as these were tested.

Some evidence secured suggested that a longer experiment period would have given lower minima than those given during the 10-day period.

While the slope of the temperature curve for rooting for supra-optimal temperatures appeared to be much influenced by oxygen and water conditions, this influence was not pronounced for sub-optimal temperatures.

Neither injurious nor beneficial effects on rooting appeared from exposing the cuttings to oxygen at a pressure of about 1 atmosphere. When ordinary air was passed through the test chamber at an adequate rate, the rooting in apple cuttings was just as satisfactory as when oxygen with only slight admixture of nitrogen was used.

Rooting values were higher when the cuttings had been subjected to an initial treatment with water, but the extent of such treatment might be excessive, in which case retardation was more or less pronounced, seemingly according to the de-

gree of excess. Thus, soaking the cuttings one hour in water resulted in increased rooting, with other conditions good, but soaking them 48 hours resulted in marked retardation of rooting. On the other hand, callusing seems to have been retarded by any water treatment, this retardation being approximately proportional to the degree of water treatment.

Callusing seems to have been more active at slightly higher temperatures and with somewhat lower water and oxygen supplies than those inducing the most active production of roots.

Although the maximum temperature for callusing was about the same as that for rooting and the optimum was only slightly above that for rooting, the minimum temperature for callusing was generally from 4° to 8° above the corresponding temperature for rooting in the same experiment.

With good environmental conditions, callus formation was generally found to be more active at the base than at the top of a cutting. This suggests an internal influence of polarity on callusing, in which respect callusing seems to differ from rooting, for which no such influence was apparent.

A distinct retardation of callusing appeared when the cuttings were surrounded with oxygen at a pressure of about 1 atmosphere, but no such retardation was observed in the case of rooting.

Although both rooting and callusing were more active at the season of the year when buds are ready for development (March), this increased activity in root and callus formation was as apparent for cuttings without buds as for those with buds; thus there seemed to be no direct influence exerted by buds on either rooting or callusing.

For formation of lenticel callus some oxygen seems to have been necessary, but the amount of oxygen required for lentical callusing was much less than for top or base callusing.

Results with Willow Cuttings.—In general, the results with willow cuttings were similar to those with apple, with some quantitative differences apparent in the cardinal temperatures and in the oxygen and water relations. The chief points of difference shown by willow cuttings were as follows:

Although for the rooting of willow cuttings an optimum temperature of about 29° C. was indicated, similar to that shown for apple, all temperatures tested between 20° and 33° were very good for willow.

Although some seasonal variation was observed, similar to that in apple cuttings, in all cases the minimum temperature appears to have been several degrees higher for rooting of willow.

All water treatments employed seemed beneficial to willow rooting; with a greater degree of water treatment, proportionally more rooting was apparent.

The minimum oxygen supply for rooting and callusing was so low that oxygen deficiency was not evident except in some of the experiments without flowing gases.

When no water treatment was used, a large oxygen supply seemed slightly to retard rooting. There was even some suggestion that the minimum temperature might be raised by oxygen excess.

Top and base callusing seems to have been more influenced in willow than in apple by excess of oxygen.

LITERATURE CITED

(1) Boehm, J.
1867. physiologische bedingungen der bildung von nebenwurzeln bei stecklingen der bruchweide. Sitzber. Akad. Wiss. Wien, Math. Naturw. Kl. Abt. 1, 56: 729–744.

(2) ———
1874. über das keimen von samen in reinem sauerstoffgase. Sitzber. Akad. Wiss. Wien, Math. Naturw. Kl. Abt. 1, (1873) 68: 132–141.

(3) Cannon, W. A.
1925. physiological features of roots, with especial reference to the relation of roots to aeration of the soil. 168 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 368.)

(4) Corbett, L. C.
1897 the development of roots from cuttings. W. Va. Agr. Expt. Sta. Ann. Rpt. (1895/96) 9: 196–199.

(5) Curtis, O. F.
1918. stimulation of root growth in cuttings by treatment with chemical compounds. N. Y. Cornell Agr. Expt. Sta. Mem. 14, p. 71–138, illus.

(6) Grau, E.
1917. UNTERSUCHUNGEN ÜBER DIE REGENERATION DER VEGETATIONSPUNKTE AN ABGESCHNITTENEN SPROSSEN IM HINBLICK AUF DIE BILDUNG DER PFROPFBASTARDE. 74 p., illus. Königsberg. (Inaug. Diss.)
(7) Hitchcock, A. E., and Zimmerman, P. W.
[1927]. VARIATION IN ROOTING RESPONSE OF CUTTINGS PLACED IN MEDIA OF DIFFERENT $_{p}$H VALUE. Amer. Soc. Hort. Sci. Proc. (1926) 23: 383–390, illus.
(8) Hutchins, L. M.
1926. STUDIES ON THE OXYGEN-SUPPLYING POWER OF THE SOIL TOGETHER WITH QUANTITATIVE OBSERVATIONS ON THE OXYGEN-SUPPLYING POWER REQUISITE FOR SEED GERMINATION. Plant Physiol. 1: 95–150, illus.
(9) Knight, R. C.
1926–27. THE PROPAGATION OF FRUIT TREE STOCKS BY STEM CUTTINGS. Jour. Pom. and Hort. Sci. 5: 248–266; 6: 47–60.
(10) Lehenbauer, P. A.
1914. GROWTH OF MAIZE SEEDLINGS IN RELATION TO TEMPERATURE. Physiol. Researches 1: 247–288.
(11) Lek, H. A. A. van der.
1925. OVER DE WORTELVORMING VAN HOUTIGE STEKKEN. Meded. Landbouwhoogesch. (Wageningen) v. 28, no. 1, 230 p., illus. (English summary, p. 211–230).
(12) Livingston, B. E., and Fawcett, H. S.
1920. A BATTERY OF CHAMBERS WITH DIFFERENT AUTOMATICALLY MAINTAINED TEMPERATURES. Phytopathology 10: 336–340.
(13) ——— and Free, E. E.
1917. THE EFFECT OF DEFICIENT SOIL OXYGEN ON THE ROOTS OF HIGHER PLANTS. Johns Hopkins Univ. Circ. 293: 182–185.
(14) Priestley, J. H.
1926. PROBLEMS OF VEGETATIVE PROPAGATION. Jour. Roy. Hort. Soc. 51: 1–16, illus.
(15) Simon, S.
1908. EXPERIMENTELLE UNTERSUCHUNGEN ÜBER DIE DIFFERENZIERUNGSVORGÄNGE IM KALLUSGEWEBE VON HOLZGEWÄCHSEN. Jahrb. Wiss. Bot. 45: 351–478, illus.
(16) Smith, E. P.
1926. ACIDITY OF THE MEDIUM AND ROOT PRODUCTION IN COLEUS. Nature 117: 339–340.
(17) Swingle, C. F.
1925. BURR-KNOT OF APPLE TREES. ITS RELATION TO CROWNGALL AND TO VEGETATIVE PROPAGATION. Jour. Heredity 16: 313–320, illus.
(18) ———
1925. THE PROPAGATION OF APPLE VARIETIES BY CUTTINGS. Science (n. s.) 62: 544.
(19) ———
[1926]. THE USE OF BURR-KNOTS IN THE VEGETATIVE PROPAGATION OF APPLE VARIETIES. Amer. Soc. Hort. Sci. Proc. (1925) 22: 228–230.
(20) ———
[1927]. A QUANTITATIVE STUDY OF THE EFFECTS OF TRANSPLANTING AND OF BUDDING UPON THE GROWTH OF APPLE SEEDLINGS. Amer. Soc. Hort. Sci. Proc. (1926) 23: 99–104.
(21) ———
1927. BURRKNOT FORMATION IN RELATION TO THE VASCULAR SYSTEM OF THE APPLE STEM. Jour. Agr. Research 34: 533–544, illus.
(22) Trécul, A.
1846. RECHERCHES SUR L'ORIGINE DES RACINES. Ann. Sci. Nat. Bot. (3) 6: 303–345, illus.
(23) Vöchting, H. von.
1878, 1884. ÜBER ORGANBILDUNG IM PFLANZENREICH. 2 v., illus. Bonn.
(24) Zimmerman, P. W.
[1926]. VEGETATIVE PLANT PROPAGATION WITH SPECIAL REFERENCE TO CUTTINGS. Amer. Soc. Hort. Sci. Proc. (1925) 22: 223–228.

OCCURRENCE OF THE ZONATE-EYESPOT FUNGUS HELMINTHOSPORIUM GIGANTEUM ON SOME ADDITIONAL GRASSES[1]

By CHARLES DRECHSLER[2]

Associate Pathologist, Office of Horticultural Crops and Diseases (formerly with Office of Cereal Crops and Diseases), Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

In a previous paper[3] the occurrence of the zonate-eyespot fungus (*Helminthosporium giganteum* H. and W.) on more than a score of grasses was recorded and a brief description of the lesions as they appear on each host was given. The account in question incorporated the results of observation begun in 1922, when the parasite was especially destructive and abundantly distributed, and continued as occasion offered not only in the vicinity of the District of Columbia but also in various other localities during the four following seasons, all of which were marked by a considerably diminished prevalence of the fungus. The season of 1927 likewise revealed only moderate development of zonate eyespot, so that observations in the territory previously covered yielded little additional information. In 1928, however, the disease reappeared with more than ordinary severity. Its obvious destructiveness to a number of favorable hosts in the experimental grass plots at Arlington Experiment Farm, Rosslyn, Va., insured throughout August and September a liberal supply of conidia to which the other grasses under cultivation were exposed to a greater or less degree, depending, of course, somewhat on the relative distances and the positional features which the arrangement of the grounds entailed. Opportunity was thus afforded for noting especially the degree of susceptibility of a rather rich assortment of graminaceous species added to the plantings since 1922, among which many represent introductions from foreign lands where the parasite under consideration is not known to occur at present.

PRESENT INVESTIGATION

Foliar injury attributable to *Helminthosporium giganteum* was manifested in 11 grasses not hitherto recorded as hosts of that parasite. The determination of *H. giganteum* as the causal agent was accomplished through the identification either of fructifications growing out of the lesions or, in the case of the more unfavorable hosts, of the adhering evacuated conidial membrane, which from its position relative to the diseased tissue could safely be regarded as the envelope of the spore that had occasioned some particular instance of injury. It may be mentioned that two other species of Helminthosporium were present in large quantities in the experimental plots. One was the unnamed form briefly characterized in 1925[3] as a parasite of redtop (*Agrostis palustris* Huds. = *A. alba* L.) but here found energetically

[1] Received for publication Feb. 2, 1929; issued July, 1929.

[2] The writer gratefully acknowledges his indebtedness to Agnes Chase and A. S. Hitchcock for identification of various grasses discussed in the present paper and for information relating to nomenclatorial questions.

[3] DRECHSLER, C. A LEAF-SPOT OF REDTOP CAUSED BY AN APPARENTLY UNDESCRIBED SPECIES OF HELMINTHOSPORIUM. (Abstract) Phytopathology 15: 51–52. 1925.

parasitic on seaside bent grass (*A. maritima* Lam.). The other caused severe leaf spot, mostly of the spot-blotch type, of a considerable number of grasses belonging to the genera Bromus, Calamagrostis, Elymus, Festuca, and Lolium, and would seem referable to *H. sativum* P. K. and B. Although in most cases the appearance of the lesion provided a valuable clue to the identity of the species of Helminthosporium involved, it could not be relied on sufficiently to obviate the necessity of procedure more trustworthy than macroscopic inspection. Thus a sprinkling of lesions of the simple eyespot type found on the leaves of *Calamagrostis epigeois* Roth, which strongly suggested injury from *H. giganteum*, was found attributable rather to the spot-blotch fungus. And again extensive foliar injury observed in a plot of buffalo grass (*Bulbilis dactyloides* (Nutt.) Raf.), which bore great resemblance to the zonate development of *H. giganteum*, could not be referred to any species of Helminthosporium, nor indeed to any other fungous agent, but was apparently of nonparasitic origin.

Among the various grasses severely attacked by *Helminthosporium sativum*, several bore evidence also of injury from *H. giganteum*, though the number and extent of the lesions due to the latter organism in such instances were for the most part inconsiderable. The pathological effects of the eyespot fungus on these grasses will not be discussed in the present paper, as it is hoped that in some other season a decreased development of the spot-blotch parasite, or preferably its absence, may make available a supply of less ambiguous material. In most of the plots of *Agrostis maritima* the presence of the sclerotium-forming species of Helminthosporium already referred to interposed a similar cause of confusion. However, in a few of the plantings, perhaps because of a greater degree of resistance in the host strain involved, infection from that source was present only in negligible quantity. Their close proximity to grass plots heavily infected with zonate eyespot, on the other hand, encouraged a fair representation of lesions due to *H. giganteum*, so that the reaction of seaside bent to this parasite could be observed under tolerably favorable conditions. The material used for illustrating the eyespot lesions on seaside bent, like that of the other hosts on which the presence of other parasites could be suspected, was first examined microscopically and the presence of an evacuated spore membrane of *H. giganteum* on each lesion confirmed. The likelihood of leaf spots other than those due to the zonate-eyespot fungus being included in the illustrations of this paper or in those of the preceding contribution, therefore, was effectively obviated.

In the following paragraphs the pathological effects appearing on the several grasses from exposure to *Helminthosporium giganteum* are briefly considered. Except when otherwise stated, the discussions are based on observations made at the Arlington Experiment Farm during August and September, 1928.

PATHOLOGICAL EFFECTS OF HELMINTHOSPORIUM GIGANTEUM ON VARIOUS GRASSES

In all plots velvet bent (*Agrostis canina* L.) was found very severely attacked by *Helminthosporium giganteum*. Because of the unusually narrow foliage characteristic of this host, the manifestation of injury is somewhat unlike that found in grasses with broad leaves. (Pl. 1, A–I.) On close inspection the incipient or small lesions, to be

sure, present the usual picture—a small, dead, bleached region surrounded by healthy green tissue. (Pl. 1, A, B.) With subsequent increase in extent as a result of secondary development, which very readily takes place under suitably moist conditions, the lesions soon occupy the entire width of the leaf. (Pl. 1, C–I.) As a result, a large proportion of the foliar organs in an actively growing stand exhibit dead segments of variable length alternating with living portions. Although in itself the destruction of segments of a leaf does not involve, at least immediately, the death of parts more distal in position, further extension of the fungus generally eventuates in the withering of the greater length of the blade affected. As the dead foliage is light-gray or light-straw colored, the general aspect of a growing turf in which the parasite has been operating for some time may be rather aptly compared to that of graying hair.

A very similar grizzly appearance is characteristic also of badly affected turf of susceptible creeping bent (*A. stolonifera* L.), especially when a narrow-leaf habit is encouraged through frequent mowing. A graying aspect is offered by diseased creeping bent even when cutting is infrequent; for, although on a close view the separate lesions can generally be distinguished on the somewhat broader leaves as discrete spots (pl. 1, T–Y; A′–J′), at a distance of 1 meter or more their individuality as well as that of the numerous completely withered leaves (pl. 1, Z) is much less apparent and thus becomes subordinate to the general appearance.

Information is not available as to whether the zonate eyespot is prevalent on velvet bent in the region, including especially the Northeastern States, where the grass is utilized in an economic sense both in ordinary lawns and more particularly as turf for golf courses. The section referred to is well north of the presumptive natural range of the disease, as far as the limits of that range may be surmised from the few collections which the writer has made. In this connection it may be pertinent to refer again to the discovery of *Helminthosporium giganteum* in various localities in Michigan, Minnesota, northern Ohio, northern Indiana, and northern Illinois, although no infection of other favorable hosts growing under ordinary natural conditions was found in those instances where a search was made. That the commercial distribution of infected stolons from sources within the natural range of the parasite may be held largely responsible for such northern occurrence can hardly be doubted. The distribution of velvet bent, however, has been almost wholly by seed, although a very limited traffic in material for vegetative propagation seems to have taken place in recent years. Because of its small size and the somewhat prolonged storage regularly entailed in commercial handling, bent seed would seem considerably inferior to stolons as a vehicle for the transmission of a fungus of apparently only ordinary hardiness. The human agencies operating in favor of a wide artificial distribution of the parasite in the case of creeping bent may, therefore, not have been equally effective in the case of velvet bent.

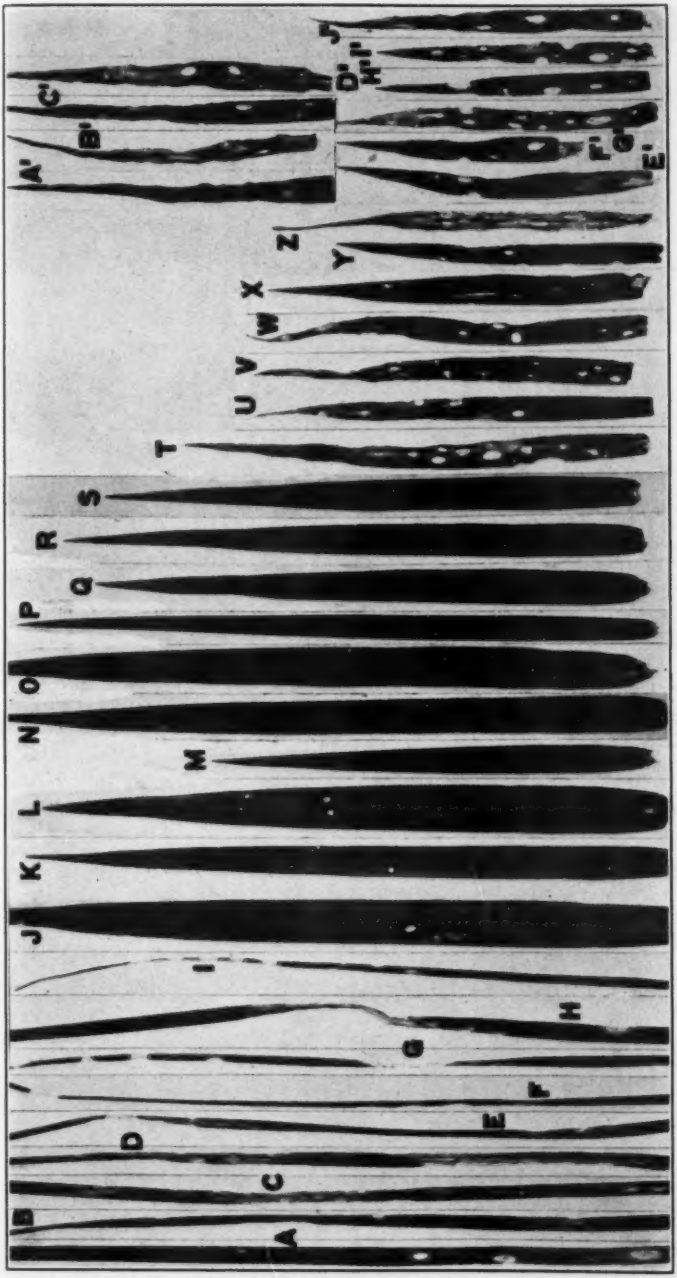
On the other hand, if the strains of velvet bent cultivated at Arlington Experiment Farm may be taken as representative of the species, this grass, once the parasite is established in a green, would suffer presumably quite as severely as the most susceptible selections of creeping bent. Irrespective of the kind of grass employed, the

conditions provided in putting greens, of course, are unusually favorable for the fungus. The frequent watering necessitated in the management of a satisfactory turf enables the parasite to extend its lesions and to continue producing conidiophores and conidia in quantity regardless of the intervention of droughty periods. Local distribution of conidia—a feature in respect to which the fungus would seem less successful under natural conditions than most of its graminicolous congeners—is undoubtedly promoted very materially by mechanical operations like mowing, rolling, or the removal of dew. Moreover, the extended season (from early in spring until late in fall) through which turf is kept in active vegetative condition can not but operate especially to the advantage of a pathogene somewhat slow in developing its attack.

Agrostis maritima, growing in close proximity to very badly infected creeping bent, displayed only a relatively small number of lesions due to *Helminthosporium giganteum*. These lesions were of the simple eyespot type, relatively small, usually not measuring more than 0.5 mm. in length and 0.2 mm. in width, though occasionally attaining dimensions somewhat more than twice as great. (Pl. 1, J–S.) Even macroscopically the injury due to *H. giganteum* could usually be distinguished from spots attributable to the congeneric parasite so abundant on the same species of grass by their smaller size and especially by the relative proportion of central bleached tissue to the width of colored margin. In the main, the central areas of lesions due to *H. giganteum* were bleached rather completely, the contrast with the surrounding tissue being pronounced and the line of demarcation well defined, and the colored margin was comparatively narrow. On the other hand, the lesion caused by the other species of Helminthosporium consisted of a somewhat more vaguely defined, less completely bleached area surrounded usually by a wide zone of dull reddish coloration. It is hardly necessary to add that conidiophores of *H. giganteum* were never observed on the feebly attacked foliage of seaside bent, and that the latter, as far as present observations may be trusted, would not serve as host in the absence of other grasses.

Eragrostis caroliniana (Spreng.) Scribn. was found heavily attacked by *Helminthosporium giganteum*. (Pl. 2, A–W.) In the beginning individual infections were manifested in lesions of the eyespot type, which were often not more than 0.3 mm. in width and 0.5 mm. in length, and which had minute bleached centers delimited from the healthy tissue by moderately broad dark-brown or purplish-brown zones. (Pl. 2, E, K, N, O, R, W.) Subsequent enlargement of the diseased areas through centrifugal extension of the parasite occurred readily, not only bringing about malformations in younger leaves, traceable to locally impeded growth (pl. 2, B, C, M, S, L, T), but also eventually resulting in the complete or partial destruction of the foliar organ. (Pl. 2, B, G, I, L, P, Q, T, U.) Such destruction was apparent usually as a progressive withering of the affected leaf from tip toward base. As microscopic inspection of the dead tissue revealed an abundance of conidial fructifications of the parasite, there can be no doubt that *E. caroliniana* is to be reckoned among the more congenial hosts on which the parasite can maintain itself without difficulty.

Festuca hookeriana (Benth.) Müll. (=*Schedonorus hookerianus* Benth.), a grass that plays a part in the agriculture of New South

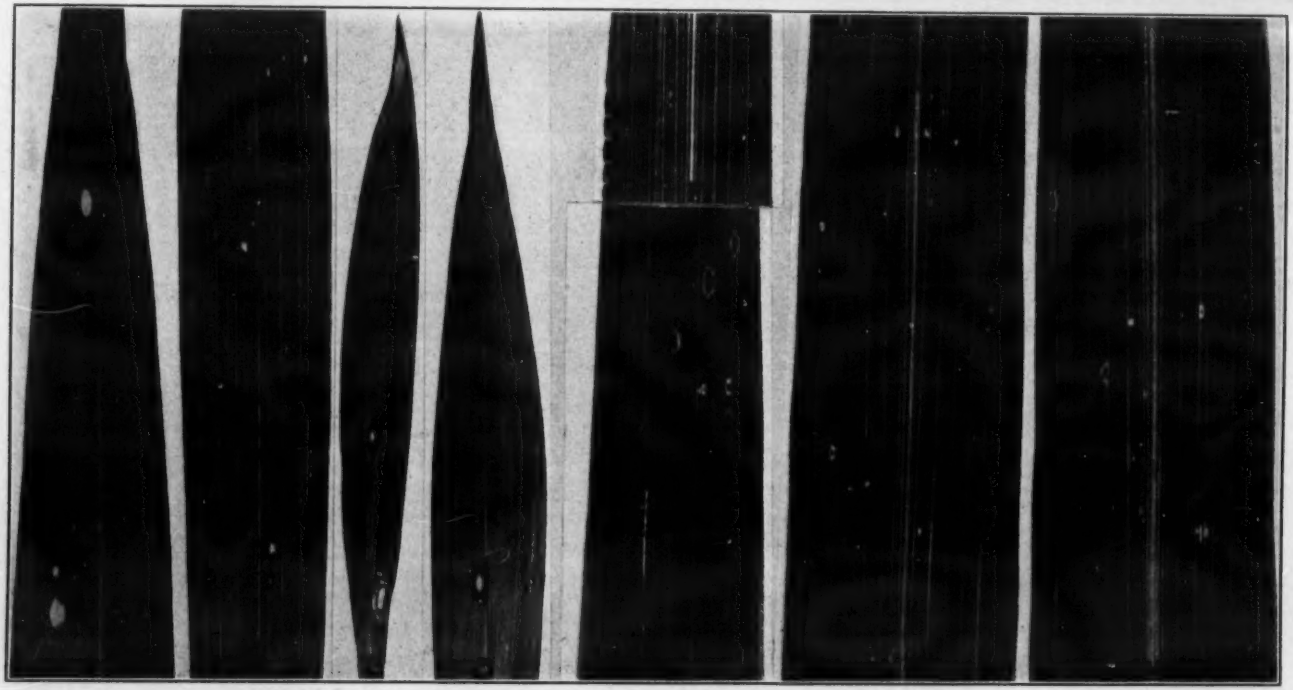


Leaves of grasses attacked by *Helminthosporium gigantrum*, × 2: A–I, *Agrostis canina*; J–S, *A. maritima*; T–Z and A'–J', *A. stolonifera*

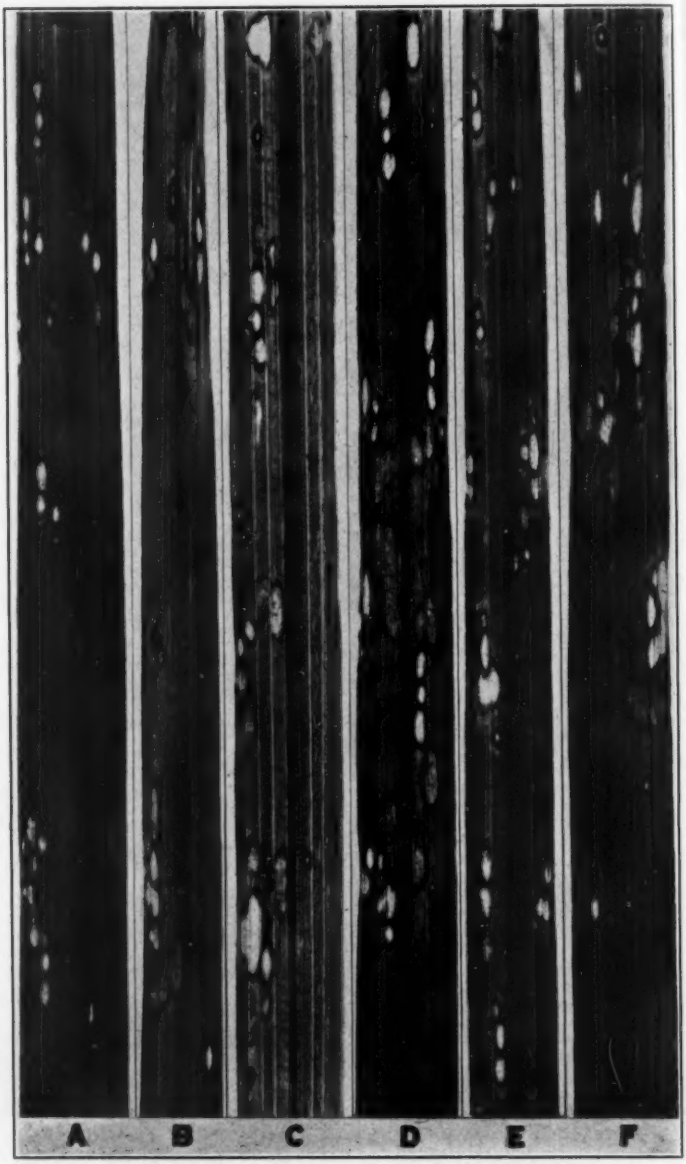
Leaves of grasses attacked by *Helminthosporium digwteum*, × 2: A–W, *Eragrostis carolinana*; X–Z and A'–D', *Festuca hookeriana*

Leaves of grasses attacked by *Helminthosporium giganteum*, × 2: A and B, *Iropkorus unisetus*; C, *Pennisetum ciliare*; D–F, *Phalaris bulbosa*

Leaves of grasses attacked by *Helminthosporium gigantcum*, × 2: A and B, *Phalaris bulbosa*; C-J, *P. stenoptera*; K and L, *Spodiopogon sibiricus*



Leaves of grasses attacked by *Helminthosporium giganteum*, × 2: A–D, *Spodipogon sibiricus*; E–H, *Tripsacum dactyloides*



Leaves of *Sporobolus* sp. (S. P. I. No. 75378) attacked by *Helminthosporium giganteum*, × 2: A–D, series showing fresh peripheral infection in water-soaked stage present in increasing quantity; E, lesions abundant but with little zonal extension in progress; F, two zonate lesions with fresh peripheral increments; the other lesions show no current enlargement

Wales, Australia, somewhat comparable to that played in the United States by the brome grasses utilized here, was found spotted liberally with lesions due to attack by *Helminthosporium giganteum*. (Pl. 2, X–Z; A′–D′.) These were evident often as minute dark-brown spots sometimes not exceeding 0.1 mm. in width and 0.5 mm. in length. (Pl. 2, X, Y.) Occasionally the unrelieved eyespot type of discoloration persisted even in the largest of morbid regions with a width of approximately 1 mm. and a length of 4 mm. (Pl. 2, X, A′, and D′.) More generally, however, the larger number of all except the smallest lesions revealed sharply delimited, somewhat bleached central areas, often so minute as to be barely discernible, but in instances of better development sometimes attaining widths of 0.5 mm. and lengths of 1 mm. (Pl. 2, Z, B′ and C′.) In the resultant eyespot arrangement the dark-brown marginal zone was often, though not always, rather broad in comparison with the size of the central straw-colored portion. Distinctive zonate development was never observed, and microscopic examination uncovered no evidence of sporophores of *H. giganteum* arising from the discrete areas of affected tissue. It is hardly possible, therefore, that under ordinary conditions the grass would serve as a host of the parasite independently of other grasses. However, the abundance in which infection occurred would suggest that, under especially favorable conditions, with perhaps more extensive areas of morbid tissue resulting from the coalescence of separate lesions, the production of conidiophores and conidia might take place.

Ixophorus unisetus (Presl.) Schlecht, a native of Mexico, became marked in a somewhat unusual manner as a result of infection by *Helminthosporium giganteum*. The deep marginal discoloration evident in many hosts was represented on the upper aspect of the leaf by a blotch of purplish hue fading gradually into the green of the surrounding healthy tissue. In Plate 3, A and B, these purplish blotches are represented rather inadequately by the vaguely delimited dark regions surrounding the elliptical patterns, though their considerable extent is not inaccurately shown; the blotch exhibited near the upper left corner of Plate 3, B, for example, measures approximately 16 mm. in length and 7 mm. in width. The elliptical patterns consist, as the illustrations indicate, of outer zones of light coloration surrounding central regions of darker coloration, the former being of a light brownish hue and the latter of a darker reddish-brown or nearly brick-red color. The undersurface of the infected leaf generally exhibited no evidence of purple discoloration, but it did exhibit the reddish brown in the area corresponding to the central region, though usually in a slightly paler tone. The light-brown tone was represented on the undersurface only by a faintly colored halo separating the elliptical brown region from the green of the adjacent normal leaf tissue. In spite of the somewhat pronounced chromatic effects produced by the fungus, microscopic inspection failed to reveal any indication of conidiophores on any of the material examined. From the information available, therefore, *I. unisetus* can hardly be regarded as a sufficiently congenial host to propagate the fungus in the absence of other grasses.

On the leaves of *Pennisetum ciliare* (L.) Link were found a small number of longitudinally elongated dark-brown blotches attributable from microscopic examination to the germination of conidia of *Helminthosporium giganteum*. One of the largest of these lesions,

approximately 4 mm. in length and 1 mm. in width, is represented in Plate 3, C. Some of the blotches had bleached central parts, thus bringing about a somewhat poorly defined eyespot effect. Conidiophores were never observed. Evidently the grass under consideration, like the congeneric *P. alopecuroides* (L.) Spreng., is far too uncongenial as a host to support the parasite in the absence of more susceptible species.

Phalaris bulbosa L. bore a meager sprinkling of lesions, associated with overlying conidia of *Helminthosporium giganteum*. (Pl. 3, D–F and pl. 4, A, B.) Except for the incipient stages (pl. 4, B), the infections adhered to the eyespot type, a minute bleached speck being discernible often in examples not exceeding 0.7 mm. in length or 0.2 mm. in width. (Pl. 3, D, E.) In the larger examples measuring up to 2 mm. in length and 0.7 mm. in width, bleached center and dark-brown margin usually appeared in sharp contrast with each other and with the adjacent healthy tissue. (Pl. 3, F and pl. 4, A.) Conidiophores of the parasite were never observed on any of the affected leaves examined. However, the production of such structures could not well be expected from morbid tissue so inconsiderable in quantity. The independent propagation of the parasite on the host in question would seem altogether improbable.

A substantially identical reaction to the presence of *Helminthosporium giganteum* was observed on the congeneric and very similar *Phalaris stenoptera* Hackel. To be sure, an appreciably greater abundance of lesions is evident in the illustrations of the latter host (pl. 4, C–J) but this is to be attributed to the fact that the material utilized here consisted of leaves that had grown intermingled with badly infected foliage of *P. arundinacea* L. and had consequently been exposed most rigorously to conidia of the parasite. Indeed, if allowance is made for the obvious disparity in the severity of exposure, it is not certain that *P. stenoptera* might not be regarded as inherently of somewhat less rather than of greater susceptibility than *P. bulbosa*. In any case conidial fructifications of *H. giganteum* were as completely absent as in the latter species, and an approximately equal incapacity for the independent propagation of the fungus is indicated.

Spodipogon sibericus Trin. exhibited a relatively meager sprinkling of foliar lesions of the simple eyespot type attributable to infection by *Helminthosporium giganteum*. (Pl. 4, K, and pl. 5, A–D.) Bleached central parts were evident in some of the lesions that measured only 0.5 mm. in length and 0.2 mm. in width. (Pl. 5, A, B.) In the largest lesions observed, the dimensions of which were about six times as great, the elliptical cream-colored central areas were delimited rather sharply by the dark-brown or purplish-brown borders. (Pl. 4, L, and pl. 5, A, C, D.) In some instances a purplish discoloration appeared diffused in the tissue for some distance above and below the distinctly morbid part, a condition that may have been expressive of a certain measure of centrifugal infection. Under especially favorable conditions the host would seem to permit zonate development, although only to a slight extent, the halos surrounding the two larger lesions in Plate 5, A, and the grouping of the smaller lesions in Plate 5, B, being suggestive in this connection. However as microscopic examination failed to reveal presence of conidiophores on any of the affected leaves, *S. sibericus* should be considered among the more uncongenial hosts of *H. giganteum*.

An unidentified species of Sporobolus (S. P. I. No. 75378) recently introduced from Nairobi, Africa, by the Office of Foreign Plant Introduction, Bureau of Plant Industry, was revealed as one of the most favorable host of *Helminthosporium giganteum* hitherto encountered by the writer. The large number of individual lesions observed on the foliage provided evidence of a relatively low resistance to infection from germinating conidia (pl. 6, A–E), while an abundance of well-developed zonate patterns testified to the ready centrifugal extension of the parasite under suitable environmental conditions. (Pl. 6, A–F.) On microscopical inspection conidial fructifications of the parasite were found in quantity on the larger regions of killed tissue, indicating that once the parasite becomes established in a stand of this grass not only is the infection apt to become increasingly severe within the stand, but other grasses growing near by may be expected to become spotted in a measure commensurate with their proximity and inherent susceptibility. As the material used for the illustrations included in Plate 6 was collected at a time when rainy weather had prevailed during the preceding 16 hours, enlarging water-soaked zones are represented especially in Plate 6, D and F, in the somewhat poorly defined patches surrounding certain of the lesions. The more pronounced differentiation between cream-colored or straw-colored bleached areas and their delimiting dark-brown or occasionally purplish-brown borders becomes evident in this host, as in others, with the drying out of the affected tissue. The color values referred to are represented with fair approximation in the discrete lesions and older portions of zonate tracts shown in Plate 6.

Gama grass (*Tripsacum dactyloides* L.) was found very sparingly marked with incipient lesions attributable to *Helminthosporium giganteum*. (Pl. 5, E–H.) The morbid parts were manifested as brown elliptical spots, which were usually about 0.3 to 0.4 mm. in width and 1.5 mm. in length and surrounded by etiolated zones approximately 0.2 mm. in width. As might be expected in view of the inconsiderable mass of the tissue affected, the microscope revealed no sporophores of the parasite on any of the material examined. The rôle played by gama grass in the biology of the parasite, would seem, therefore, to be nearly negligible.

SUMMARY

Near Washington, D. C., 11 grasses not hitherto recorded as hosts of *Helminthosporium giganteum* were found naturally infected by it when growing under ordinary cultivation—that is, without artificial watering or other procedure that might accentuate the severity and prevalence of disease. Severe injury and abundant sporulation of the parasite was observed on velvet bent (*Agrostis canina*), a grass of some economic importance because of its usefulness in lawns and golf courses; on *Eragrostis caroliniana*, a common weed of no known value; and on an unidentified species of Sporobolus recently introduced from Nairobi, Africa, and of problematical economic utility. Readily noticeable though not severe injury, without sporulation, was observed on *Festuca hookeriana*, *Ixophorus unisetus*, and *Spodipogon sibericus*. On *Agrostis maritima*, *Pennisetum ciliare*, *Phalaris bulbosa*, *P. stenoptera*, and *Tripsacum dactyloides* only inconsiderable injury was detected, the lesions usually being both few and small.

MODIFICATION OF WESTERN YELLOW PINE ROOT SYSTEMS BY FERTILIZING THE SOIL AT DIFFERENT DEPTHS IN THE NURSERY[1]

By W. G. WAHLENBERG

Assistant Silviculturist, Northern Rocky Mountain Forest Experiment Station, Forest Service, United States Department of Agriculture

INTRODUCTION

One of the most desirable characteristics in planting stock for use in the northern Rocky Mountains is drought hardiness. To this end it is generally considered necessary that stock should have relatively small tops and large bushy root systems, and consequently some cheap and effective means of producing stock of this description has long been sought. Underground root pruning (the cutting of seedling roots in situ) and transplanting in the nursery are the principal means thus far employed. These practices have, however, some disadvantages. Underground pruning alone might be effective if better spacing of seedlings could be attained by improvements in broadcast sowing or by sowing in drills. At present the spacing of plants in seed beds that have been sown broadcast is not sufficiently uniform to permit of root pruning in place without a heavy loss in dense patches of seedlings that do not have room enough for proper response to the pruning. Transplanting has an advantage over underground root pruning in that, in addition to determining proper root length, it results in a wider and more uniform spacing of the plants; but, on the other hand, it is a very expensive practice.

The possibility still remains that some other means, which can perhaps be combined with root pruning, may be found for regulating root growth. It should be considered that root length and the distribution of lateral rootlets may have as much influence on early drought hardiness as the general bushiness of roots. If, wherever planted trees are likely to suffer severely from drought, longer roots could be planted in deeper holes these trees would undoubtedly be much hardier. However, very long roots are not practicable, since they can not be planted in the field without doubling up in the planting hole, a practice which, while it might increase survival, might do so only at the expense of later healthy development. Root pruning before planting is therefore necessary. But another means of resisting the effects of drought is the use of plants that have a large portion of the total absorbing root surface in the lower half of the root system. This points to the desirability of finding some means of developing the root system between the depths of 4 and 8 inches below the surface of the ground. In seeking such means, the investigator naturally turns his attention to the influence of soil on root development.

The root systems of tree seedlings are not necessarily typical for the species, nor so controlled by hereditary tendencies as to be incapable of modification by environmental influences. Numerous inves-

[1] Received for publication Feb. 12, 1929, issued July, 1929.

tigators have shown that at least five soil factors—moisture, fertility, physical properties, aeration, and temperature—influence the behavior of roots. Of these five, moisture and fertility are the most easily controlled in the nursery. Harris (*10*)[2] studying the behavior of corn, wheat, and peas, observed that an increase in root branching and a decrease in top-root ratio of plants was evident in the drier soils. Tucker and von Seelhorst (*19*), Jean and Weaver (*11*), and Weaver (*21*) in his study of the ecological relations of the roots of native perennial plants on prairie lands, are in general agreement. Figure 1, taken from Weaver, shows a response of the root system strikingly similar to that obtained in the present author's experiments.

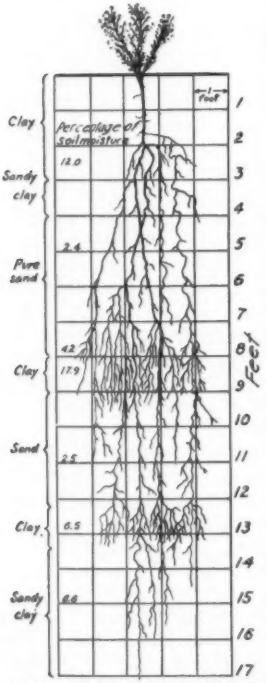


FIGURE 1.—Root system of *Kuhnia glutinosa*, after Weaver

Carlson (*6*) and Weaver (*21*) are in general agreement that hard soil encourages root branching, whereas open soil appears to stimulate the growth of taproots. The importance of soil aeration was emphasized by Saussure (*16*) more than a century ago, and more recently by Snow (*18*), Clements (*7*), Barker (*1*), Cannon and Free (*5*), and Cannon (*3, 4*). Of the few who have contributed information regarding the influence of temperature, Engler (*8*) determined the lowest temperature for root growth of conifers to be 5° to 6° C., and Vesque (*20*) made observations on the effect of high temperatures on roots.

The fifth factor influencing root growth—fertility—is one that may be controlled in the nursery, and may be directly effective. It has been noticed that roots actually seek food, but that increased root branching caused by increased soil fertility may be accompanied by an increase in the top-root ratio of plants. Von Seelhorst (*17*) concluded that liberal fertilization resulted in larger and deeper root systems of rye, wheat, barley, peas, beans, and beets. Müller-Thurgau (*13, 14*) noted that nitrogen stimulated vigorous growth of secondary roots. Märcker and Kreusler (*12, p. 94–101*) and Nobbe (*15*) saturated alternate layers of soil with nutrients and after growing clover and corn, observed that the roots branched much more freely in the rich than in the poor soil. On the other hand, Harris (*10*) found that fertilizer decreased the root growth of wheat, possibly because soil nutrients may not affect all parts of root systems in the same way or to the same extent. Bates (*2*) stated that superabundant reproduction of forest trees, on sites that are poor from the standpoint of long-term forest production, may be induced because the seedlings, half-starved for soil nutrients, root deeply and safely.

In 1924 the possibility of modifying the root form of nursery-grown trees by means of fertilization became a subject of study at the

[2] Reference is made by number (italic) to "Literature cited," p. 145.

Savenac nursery, Haugan, Mont. In this paper the results of these experiments are reviewed and discussed.

EXPERIMENTS AT SAVENAC NURSERY

METHODS OF SOWING PLOTS AND RECORDING RESULTS

In these experiments on the regulation of root growth, three 4 by 12 foot beds were used, each divided crosswise by a central board partition into two plots of 24 square feet. The soil was excavated to

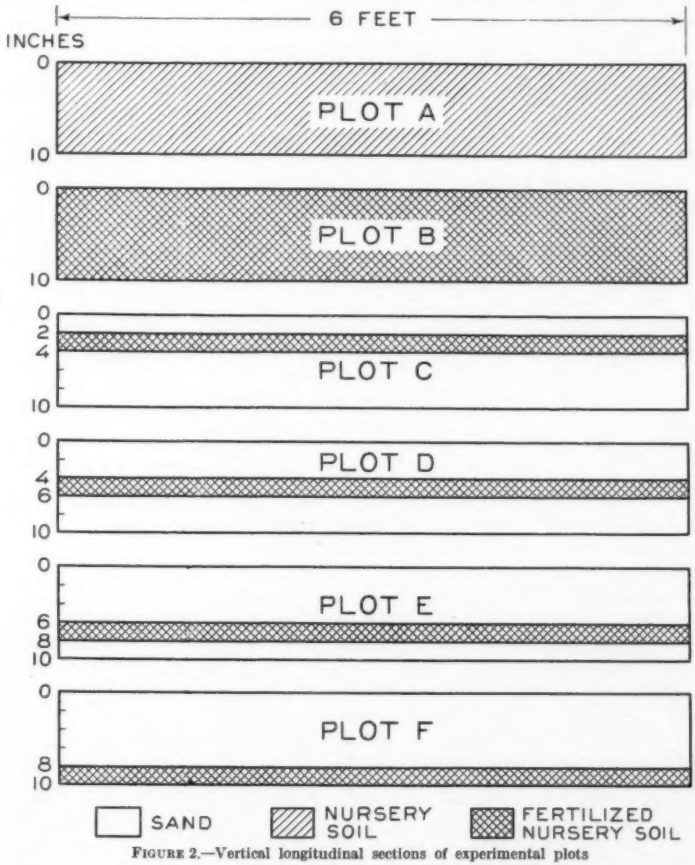


FIGURE 2.—Vertical longitudinal sections of experimental plots

a uniform depth of 10 inches, and excavations were filled with layers of sand and soil in the manner indicated in Figure 2.

The soil used in plot A was not sifted. All other soil was put through a screen having two meshes to the inch, except the small quantity used in constructing smooth sowing surfaces for plots A and B, which was sifted through a screen with three meshes to the inch. The finer of these two screens was used for sifting sand, except that

used in covering the sown seeds which was sifted through a screen of 0.1-inch mesh. These sifting processes not only provided more uniform media for root growth, but facilitated precise methods of constructing soil layers and sowing seeds. The depth of the various layers was accurately gaged by the use of special boards notched so as to slide on the lower horizontal side rails of the seed-bed frames.

The soil intended for each fertilized plot, including B, was in each instance thoroughly mixed in a box with 7½ pounds of sheep manure before placing in the plot. The fertilized soil was compacted in the measuring box by jarring and in the plots by tamping it into the desired space. Because the same quantity of fertilizer was used for plot B as for the others, concentration was less in plot B.

The sharp contrast in fertility of the 2-inch layers of manured soil with the surrounding sand was the condition sought. No measurements were made of the relative moisture-holding capacity of the two media, but samples of sand and unfertilized soil were put through sieves in order to show their difference in texture. The resulting figures given in Table 1 describe the soil materials more effectively than is possible in words.

TABLE 1.—*Mechanical soil analysis of representative samples of 407 grams of soil and 1,635 grams of sand*

Diameter of particles (millimeters)	Soil	Sand	Diameter of particles (millimeters)	Soil	Sand
	Per cent	*Per cent*		*Per cent*	*Per cent*
Over 5	0.7	6.1	Less than ½	16.6	40.3
3 to 5	7.2	12.2	Lost in process	.3	.9
2 to 3	8.8	10.7			
1 to 2	22.3	16.5	Total	100.0	100.0
½ to 1	44.1	13.3			

The subsoil below 10 inches was not moved. It consisted of gravel, sand, and considerable clay in mixture and was quite dense; but the clay apparently contained more plant food than the pure sand used in the upper soil layers.

Sowing was done on May 13, 1924, with an allowance for each plot of 10 ounces of western yellow pine (*Pinus ponderosa*) seed collected in 1923 on the Bitterroot National Forest in western Montana. Sprinkling was frequently done during the spring and early summer, to bring out germination, but was less frequently done during the second season. Wire-screen frames successfully protected the beds from outside disturbance. By the end of the second season each plot contained a good stand of seedlings.

All trees to be removed from the plots for root study were first touched with a drop of white paint at the ground line. From a trench about 3 feet deep at the end of each plot a tunnel under the trees was started, care being taken to disturb none of the soil less than 14 inches from the surface. The soil was then washed down from the roots of the seedlings and into the trench with a garden hose. By this method of removing the trees root breakage was avoided. From each of the six lots a few trees that were much inferior in general development were culled out. Most of these were from hold-over germination and a year younger than their neighbors. In the laboratory the trees were fastened to a board ruled with horizontal

parallel lines 1 inch apart and were examined in detail one at a time. The painted ground-line of each tree was made to coincide with the uppermost line of the board. Roots were allowed to fall together in a loose mass as they would when planted, no attempt being made to spread out the lateral roots in the position in which they grew. All roots more than one-fourth inch long were counted each time they crossed a line, and the counts were recorded separately for each tree and line. Every 1-inch root segment to a depth of 14 inches was thus counted for 105 trees from each of the plots. Averages from these figures are given in Table 2, which forms the basis of the curves in Figure 3, the significance of which may be more readily seen from the graphs.

TABLE 2.—*Root frequency of 2–0 western yellow pines at different depths when grown in soil with fertilized layers at various depths*

[Each column gives the averages of counts made on 105 seedlings]

Distance from surface	Number of root sections in—						Distance from surface	Number of root sections in—					
	Plot A	Plot B	Plot C	Plot D	Plot E	Plot F		Plot A	Plot B	Plot C	Plot D	Plot E	Plot F
Inches							*Inches*						
1	1.1	1.0	1.1	1.0	1.1	1.0	9	5.7	3.5	3.0	3.1	7.0	8.3
2	2.8	2.8	3.0	2.1	2.6	2.3	10	5.2	2.9	2.3	2.4	5.2	9.1
3	5.4	5.8	6.3	3.8	4.8	4.0							
4	7.7	8.6	10.2	5.0	6.9	6.2							
5	8.5	8.9	11.1	8.2	8.0	7.4	11	4.9	2.7	3.5	3.0	6.3	9.1
6	8.4	7.6	7.6	8.9	7.6	7.9	12	3.2	2.0	3.0	2.3	6.4	8.9
7	7.7	6.0	5.2	6.5	9.5	7.8	13	2.3	1.7	2.6	1.3	5.1	7.6
8	6.5	4.8	3.9	4.4	9.6	7.8	14	1.6	1.5	2.2	1.2	3.2	5.6

Measurements were also made to determine the effect of the fertilization on the plant tops. The figures given in Table 3 show the tendency of fertilizer, especially in the deeper 2-inch layers of rich soil, to produce large tops.

COMPARISON OF RESULTS

In Figure 3 the curves for plots A and B may be taken to indicate the typical root development of 2-year-old western yellow pine seedlings. The general shape of the curves suggests the obconical, or inverted cone form, of which Haasis (*9*) speaks. The slight swelling in each of these curves below the 10-inch depth indicates a slight stimulation of root growth upon entering the subsoil. The average total mass of roots was greater on the trees from plot A than on the trees from plot B.

TABLE 3.—*Dimensions of western yellow pines grown in soils enriched at various depths below the surface*

[Figures are averages based on the measurement of 120 trees from each plot]

Plot	Treatment	Diameter at ground	Height from ground to tip of bud	Plot	Treatment	Diameter at ground	Height from ground to tip of bud
		Mm.	*Inches*			*Mm.*	*Inches*
A	Nursery soil	1.0	2.0	E	Rich layer 6 to 8 inches below surface	1.3	2.3
B	Fertilizer distributed	1.1	2.2	F	Rich layer 8 to 10 inches below surface	1.4	2.7
C	Rich layer 2 to 4 inches below surface	1.2	2.2				
D	Rich layer 4 to 6 inches below surface	1.1	2.1				

The tree roots from plot C form a similar curve with its greatest crest about 5 inches from the ground line, but these trees averaged 11 roots at that depth as compared with 8 or 9 on the same level in plots A and B, and root stimulation in the subsoil seems to have

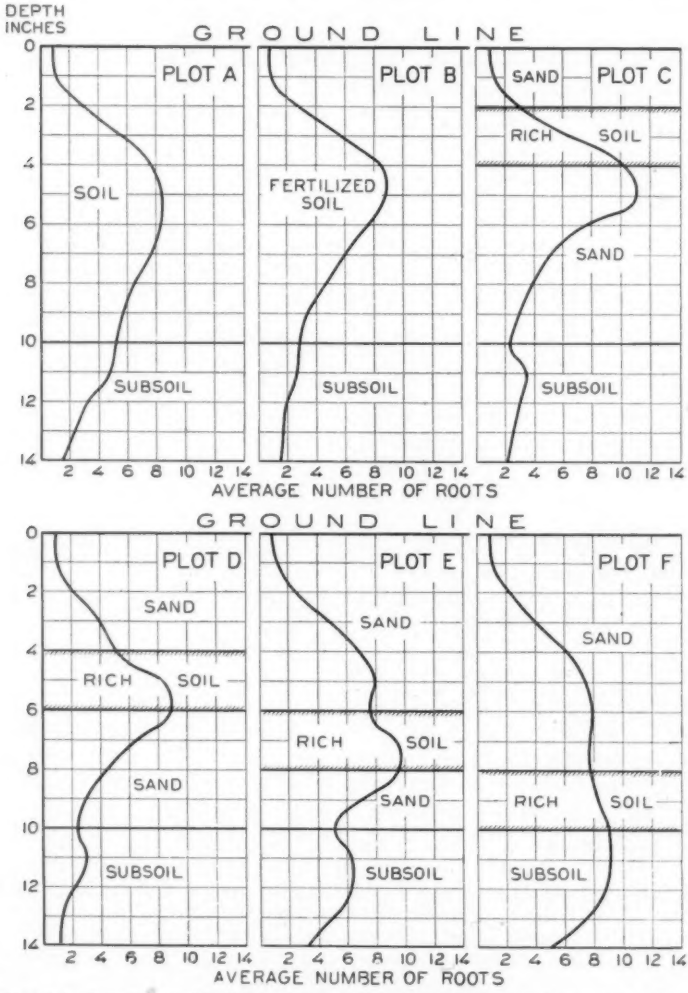


FIGURE 3.—Influence of soil fertility on the number of western yellow pine seedling roots at various depths. Each curve is based on the growth of fifty 2-0 plants

been greater in plot C. How these differences may be directly traced to the sharp contrasts in the soil medium will be made clear as the other curves are studied.

One question is natural here. If the increase in size and sharpness of the major crest in curve C is to be ascribed to the presence of the

2-inch layer of rich soil, why is it not centered in that layer 2 inches nearer the surface? It is not enough to note that the crests of the more natural curves A and B are at the same level. Three auxiliary reasons may be given: (1) Downward percolation of plant nutrients in the soil solution exceeded upward movement by capillarity, so that the zone around 5 inches deep became rich in plant food; (2) root growth that started under most favorable conditions in the rich layer continued downward into the 5-inch zone and affected the counts of root segments there; (3) roots that spread widely and approached the horizontal in the rich layer increased the root counts in the layer below when allowed to fall into more nearly vertical positions on the counting board. For these reasons it is found that the response of root growth to layers of rich soil are manifest in the curves in the lower part of, or just below, the layer of rich soil itself.

In the curve for plot D the major crest comes at the lower edge of the rich layer at the 6-inch depth. This is about an inch deeper than the natural crests of curves A and B, and hence the natural and artificial crests in curve D do not completely merge. This is indicated by the slight swelling at the 3-inch and the slight depression in the curve at the 4-inch depth. As in curve C, the response to subsoil in curve D is marked.

In the curve for plot E the position of the artificially produced crest bears much the same relation to the rich layer as in the other plots, but here it is low enough to be distinct from the natural crest, which shows again in its usual position 5 inches from the surface. The subsoil crest is present as before.

In plot F the rich layer was placed just above the subsoil. As the curve indicates, this position was so low as to cause the crest from rich soil to merge completely with that from the subsoil, so that the curve has two crests, the usual one above and the one produced by artificial means below, with a depression between at the 6 to 8 inch depth. Curves for plots E and F both indicate relatively large numbers of roots in the deeper layers of soil. Root increases in the subsoil in these plots appear to be largely due to branches which started growth in the rich soil not far above.

The above-mentioned characteristics of the root-frequency curves all seem to be consistent except one. If rich soil favors root branching and subsequent root growth, as is apparent in most of the plots, why should the root mass have been greater in the trees from unfertilized plot A than in those from fertilized plot B? The other soil factors known to influence roots—moisture, physical properties, aeration, and temperature—must have been much the same in the two plots, except as the small amount of fertilizer in plot B changed them. The fertilizer in plot B would make the soil slightly more retentive of moisture than that of plot A, thus tending to reduce the relative root growth of plot B, other things being equal. This reasoning may explain the behavior of the soil plots (A and B), but not that of the sand plots (C, D, E, and F). Possibly the cause of the inconsistency is a matter of general nutrition. The trees in soil grew in a natural medium with sufficient nutrient for ordinary needs, whereas the trees in sand were in a state of semistarvation and hence local root response was stimulated for the benefit of the plants as a whole. Unfortunately no plot was made of ordinary nursery soil containing a rich layer.

Whatever may be the true cause of this exception, the experiment seems to show the possibility of modifying root systems in the desired direction. The most desirable form of root system resulted from fertilized layers of soil 6 to 10 inches deep.

STUDIES IN FIELD PLANTATIONS

The extent to which the foregoing results obtained in the nursery affected the survival of trees planted in the field was tested. Two plantations each of western yellow pines from the six experimental plots were made on land typical of the burned-over areas in need of reforestation in the region. Just before planting all roots were pruned at a point 8 inches from the ground line, because longer roots could not be planted economically by the usual methods and with the customary tools. The first plantation was made in October, 1925, on a southeast slope with four hundred 2-year seedlings from each of the six plots. It was examined on August 25 of the following year. Although the plants were somewhat small for field use, by reason of the low average fertility of the seed beds and some crowding of seedlings, they served the purpose of the experiment.

In 1926 a similar plantation of 200 larger 3-year seedlings from each plot was made on a northwest slope, and was examined on September 16 of the following year—1927. The growing season of 1926 was one of drought; that of 1927 was moist. Thus, three conditions account for the generally higher survival of the second plantation, as shown in Table 4—the larger and better-developed seedlings, the more favorable site, and the more abundant moisture.

TABLE 4.—*Effect of modified root systems on the survival of western yellow pine seedlings one year after planting in the field*

[Based on a plantation of four hundred 2-0 and two hundred 3-0 seedlings from each of the six nursery plots. Average survival percentages were rounded off to the nearest whole number from basic figures carried to one decimal place]

2-0 SEEDLINGS PLANTED ON A SOUTHEAST SLOPE, OCTOBER 8 TO 12, 1925

Nursery plot	Depth of fertilization	Alive		Thrifty	Unthrifty
	Inches	*Per cent*		*Per cent*	*Per cent*
A	0	18	22	17	2
B	0 to 10	26		23	3
C	2 to 4	30	28	29	1
D	4 to 6	26		24	2
E	6 to 8	47	44	45	2
F	8 to 10	42		40	2

3-0 SEEDLINGS PLANTED ON A NORTHWEST SLOPE, OCTOBER 8 AND 9, 1926

A	0	81	79	74	7
B	0 to 10	77		69	8
C	2 to 4	74	76	67	7
D	4 to 6	78		72	6
E	6 to 8	92	91	89	3
F	8 to 10	90		86	4

The relative survival in the field of the trees from the series of six plots does not show consistent increases with increases in depth of fertilization, but when the figures are grouped in pairs, the average results show a tendency toward such an increase. In all cases the

percentage survival of the deeply fertilized trees, those exposed to a rich layer in the seed bed between 6 and 10 inches below the surface and having when planted a highly developed root system between 6 and 8 inches deep, was distinctly higher. This gives evidence of the actual superiority of such trees for planting.

CONCLUSION

From experiments at Savenac nursery in specially fertilized seed beds and from frequency curves showing relative root development according to depth of fertilizer in each bed, it has been found that the most desirable root forms of western yellow pine seedlings suitable for field planting occur in seed beds constructed with a layer of rich soil at a depth between 6 and 10 inches. Trees from such beds have highly developed root systems from 6 to 8 inches below the ground line and maintain the highest percentage of survival in field plantations.

The results clearly indicate the possibility, at least in perfectly controlled operations, of stimulating root development locally in any desired part of the root system by means of layers of rich soil. Burying fertilizers several inches deep may be expected to stimulate the growth of the lower root systems of seedlings by means of the greater contrast in zones of fertility, and at the same time to avoid certain undesirable effects near the surface of the soil such as unfavorable action on subsequent chemical treatments for the control of weeds or damping-off fungi, or interference with seed germination. But in this the operator must consider the condition of the subsoil. Deep fertilization may be wasteful whenever soil nutrients are rapidly leached out by downward percolation. At the Savenac nursery the subsoil is sufficiently impervious to prevent serious losses of this kind.

The results of the experiments herein described, although indicating certain possibilities, are at best only suggestive. Pending further experimental work and the perfection of root pruning in place and other improvements in seedling culture, the old and expensive process of transplanting will probably continue to be a necessary part of forest-nursery practice.

LITERATURE CITED

(1) Barker, B. T. P.
1921. root development in newly planted trees. Jour. Bath and West and South. Counties Soc. (5) 15: 175–194, illus.

(2) Bates, C. G.
1926. some relations of plant ecology to silvicultural practice. Ecology 7: 469–480.

(3) Cannon, W. A.
1915. soil aeration and root-growth. Carnegie Inst. Wash. Yearbook 14: 63–64.

(4) ———
1918. modification of root habits by experimental means. Carnegie Inst. Wash. Yearbook 17: 83–85.

(5) ——— and Free, E. E.
1917. the ecological significance of soil aeration. Science (n. s.) 45: 178–180.

(6) Carlson, F. A.
1925. the effect of soil structure on the character of alfalfa root-systems. Jour. Amer. Soc. Agron. 17: 336–345, illus.

(7) Clements, F. E.
1921. aeration and air content. the rôle of oxygen in root activity. 183 p. Washington, D. C. (Carnegie Inst. Wash. Pub. 315).

60654—29——5

(8) ENGLER, A.
1903. UNTERSUCHUNGEN ÜBER DAS WURZELWACHSTUM DER HOLZARTEN. Mitt. Schweiz. Centralanst. Forstl. Versuchsw. 7: [247]–317, illus.
(9) HAASIS, F. W.
1921. RELATIONS BETWEEN SOIL TYPE AND ROOT FORM OF WESTERN YELLOW PINE SEEDLINGS. Ecology 2: 292–303, illus.
(10) HARRIS, F. S.
1914. THE EFFECT OF SOIL MOISTURE, PLANT FOOD, AND AGE ON THE RATIO OF TOPS TO ROOTS IN PLANTS. Jour. Amer. Soc. Agron. 6: 65–75.
(11) JEAN, F. E., and WEAVER, J. E.
1924. ROOT BEHAVIOR AND CROP YIELD UNDER IRRIGATION. 66 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 357).
(12) MÄRCKER, M., and KREUSLER, U.
1868. VERHANDLUNGEN. DER IV WANDERVERSAMMLUNG DEUTSCHER AGRICULTURCHEMIKER, PHYSIOLOGEN UND VORSTÄNDE DER VERSUCHSSTATIONEN. Landw. Vers. Sta. 10: [81]–142.
(13) MÜLLER-THURGAU, [H.]
1895. PFLANZENPHYSIOLOGISCHES UND GÄRUNGSTECHNISCHES LABORATORIUM. 1. EINFLUSS DES STICKSTOFFS AUF DIE WURZELBILDUNG. Jahresber. Deut.-Schweiz. Vers. Sta. u. Schule Obst-, Wein- und Gartenbau in Wädensweil (1893/94) 4: 48–52.
(14) ———
1900. PFLANZENPHYSIOLOGISCHES UND GÄRUNGSTECHNISCHES LABORATORIUM. 1. UNTERSUCHUNGEN ÜBER DAS WURZELLEBEN DER PFLANZEN. Jahresber. Deut.-Schweiz. Vers. Sta. u. Schule Obst-, Wein- und Gartenbau in Wädensweil (1897/98) 8: 79–82.
(15) NOBBE, F.
1862. UEBER DIE FEINERE BERÄSTELUNG DER PFLANZENWURZEL. EINE VEGETATIONSTUDIE. Land. Vers. Sta. 4: 212–224.
(16) SAUSSURE, T. DE
1804. RECHERCHES CHIMIQUES SUR LA VÉGETATION. 327 p., illus. Paris.
(17) SEELHORST, C. VON
1902. BEOBACHTUNGEN ÜBER DIE ZAHL UND DEN TIEFGANG DER WURZELN VERSCHIEDENER PFLANZEN BEI VERSCHIEDENER DÜNGUNG DES BODENS. Jour. Landw. 50: [91]–104.
(18) SNOW, L. M.
1905. THE DEVELOPMENT OF ROOT HAIRS. Bot. Gaz. 40: 12–48, illus.
(19) TUCKER, M., and SEELHORST, C. VON
1898. DER EINFLUSS, WELCHEN DER WASSERGEHALT UND DER REICHTUM DES BODENS AUF DIE AUSBILDUNG DER WURZELN UND DER OBERIRDISCHEN ORGANE DER HAFERPFLANZE AUSÜBEN. Jour. Landw. 46: [52]–63.
(20) VESQUE, J.
1878. DE L'INFLUENCE DE LA TEMPÉRATURE DU SOL SUR L'ABSORPTION DE L'EAU PAR LES RACINES. Ann. Sci. Nat., Bot. (6) 6: [169]–201, illus.
(21) WEAVER, J. E.
1919. THE ECOLOGICAL RELATIONS OF ROOTS. 128 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 286).

THE USE OF DRESSED-BEEF APPRAISALS IN MEASURING THE MARKET DESIRABILITY OF BEEF CATTLE [1]

By JAY L. LUSH, *Texas Agricultural Experiment Station*, and W. H. BLACK, and A. T. SEMPLE, *Bureau of Animal Industry, United States Department of Agriculture*

INTRODUCTION

The most direct and obvious way of measuring the market desirability of different lots of cattle is by the prices appraised or actually paid for the live cattle by representatives of the packing companies. There are, however, several serious objections to this method, the most important of which are the following:

(1) While the total sum paid for a shipment may very closely agree with its actual market value at the time of sale, the difference in the prices paid for individual lots in the shipment may not represent fairly the real difference in the market desirability of those lots. This is accentuated by two circumstances—the common practice of selling most of the cattle at prices which vary by 25 cents per hundred pounds and the usual bargaining psychology whereby a seller who thinks that the prices offered for all the lots are a little low finds it more expedient to insist on 25 or 50 cents more for one lot than to try to get 5 or 10 cents added to the price for all lots.

(2) The live sales price does not enable one to estimate the variation in the market desirability of different steers within the same lot. All the steers in a lot either sell at the same price or in some such manner as "12 head at $8.75 with 3 out at $7.50."

(3) The buyer and salesman are both estimating the kind of dressed meat which the steers will produce and the dressing percentages which will be obtained, and occasionally rather large mistakes are made on small lots.

(4) The price level changes from day to day, and the price of a lot marketed this month can not be compared directly with the price of another lot marketed a month earlier or a month later.

The object of the present paper is to describe and illustrate a simple, inexpensive method of expressing in a single figure the market desirability of a beef carcass. This, the carcass-appraisal method, was devised before the grading-chart method (now generally used in the nation-wide cooperative study of factors which influence the quality and palatability of meat) was proposed. The appraisal method appeared to be giving good results and was not abandoned when the grading method became available. On three different occasions both methods were used, and opportunities were thus provided to compare the two methods in a limited way.

[1] Received for publication Feb. 11, 1929; issued July, 1929.

DESCRIPTION OF THE CARCASS-APPRAISAL METHOD

After the cattle are killed and the dressed beef has been in the cooler for 24 hours or more, men regularly employed by the packing company in selling meat to retailers are requested to estimate for each carcass the price which they think they could get for it in their regular sales territory. Each man makes these appraisals without consulting his associates. The carcasses are scattered about through the cooler in whatever order they are received from the killing floor. This means that they are not usually grouped together in exactly the same lots as the animals were fed. Consequently each carcass is appraised without direct reference to the other carcasses of the same lot.

On every occasion, except one shipment to Kansas City, Kans., at least three men were obtained for the appraising. The selection of men competent to appraise was made by an official of the packing company, usually the superintendent of the dressed-beef department. It was explained to this official that appraisers were wanted who had had long practical experience in the dressed-beef trade and who might be expected to recognize differences in the beef and to appraise those differences on about the same scale as the retail trade would. Since different classes of retail shops have different demands, there were usually included among the appraisers men who worked in different types of sales territory, so that the average appraisals might have a more general significance. For example, at Fort Worth, Tex., the appraising committee on several occasions consisted of one salesman whose territory was the city of Dallas, another who worked a car-route territory in northeastern Texas and southern Oklahoma, and a third who worked partly in Fort Worth and partly in car-route territory to the south and west. On several occasions the superintendent of the dressed-beef department himself acted as one of the appraisers.

Most of the appraisers had never participated in an affair of this kind and were diffident the first time about matching their judgment against that of other salesmen, especially when higher ranking officials of the packing company were present. However, it soon became evident that the estimates by the different salesmen were paralleling each other closely, and whereas on the first few occasions all, or nearly all, of the carcasses had been appraised in whole cents per pound, later many were appraised in half cents per pound, and on the last occasions many were appraised in quarter cents per pound. Statistical analysis of the data showed that the accuracy of the appraisals increased greatly with this increase in precision, and suggests that tenths or sixteenths of a cent would not be beyond the useful limit of the appraiser's ability to distinguish between the market desirability of different carcasses.

ACCURACY OF THE CARCASS-APPRAISAL METHOD

Table 1 shows the actual appraisals made for each of the first carcasses on which this method was tried, and Table 2 shows the calculations involved in measuring the accuracy of the appraisals. The method of calculation follows that given in the last two chapters of Fisher's Statistical Methods for Research Workers,[2] and is identical

[2] FISHER, R. A. STATISTICAL METHODS FOR RESEARCH WORKERS. 230 p., illus. Edinburgh and London. 1925.

with that used in a recent study of the accuracy of cattle weights.[3] The term "degrees of freedom" is used to express the number of items which are really free to show variation in the data. Since variation is figured from the mean, which is itself a calculated figure derived from the actual data, one item is required to fix the mean, and there are really only 59 degrees of freedom in the 60 original appraisals. Since there were three appraisers, 2 degrees of freedom are involved in the variation caused by the appraisers not having exactly the same price levels in mind and, when the data are corrected for this difference in the price levels used by the appraisers there remain only 57 degrees of freedom in the data. Since there were 20 carcasses, 19 degrees of freedom are involved in the variation, caused by the fact that the carcasses were not exactly alike, and when the data are corrected for the differences between carcasses only 38 degrees of freedom remain on which to estimate the error of appraisal. The 60 items of original data give us only the same amount of information about the accuracy of appraisal that would have been gained had one man appraised 39 carcasses which were absolutely identical with one another. But since it would not be possible to find a group of identical carcasses, and there would have been no way of knowing by objective methods when two carcasses were identical, the error of appraisal has to be measured in this indirect way.

TABLE 1.—*Appraised values in cents per pound of dressed carcasses of check animals killed November, 1924, at Fort Worth, Tex., at the beginning of the first Kingsville experiment*

Breed and designation number of individual steers	Appraisal estimate of—			Average
	Salesman No. 1	Salesman No. 2	Salesman No. 3	
Herefords:	*Cents*	*Cents*	*Cents*	*Cents*
55	9	9	8	8⅔
56	9	9	8	8⅔
57	12	11	11	11⅓
58	10	10	11	10⅓
59	9	9	8	8⅔
Hereford-Brahman crossbreds:				
45	9	9	8	8⅔
46	8	8	8	8
47	9	8	8	8⅓
48	10	10	9	9⅔
49	12	11	10	11
Shorthorns:				
50	7	6	6	6⅓
51	8½	8	8	8⅙
52	8	8	8	8
53	8	7	8	7⅔
54	9	9	8	8⅔
Shorthorn-Brahman crossbreds:				
60	9	9	10	9⅓
61	8	8	8	8
62	8	8	8	8
63	9	10	10	9⅔
64	8	9	8	8⅓
Average	8.975	8.800	8.550	8.775

[3] LUSH, J. L., CHRISTENSEN, F. W., WILSON, C. V., and BLACK, W. H. THE ACCURACY OF CATTLE WEIGHTS. Jour. Agr. Research 36: 551-580. 1928.

TABLE 2.—*Calculations of the accuracy of the appraisals shown in Table 1*

[Analysis of variance]

Cause of variation	Degrees of freedom [a]	Standard deviation (cents per pound)	Mean variance per degree of freedom	Total variance
All causes	59	1.237	1.5290	90.212
Difference in appraisers' price levels	2	.....	.9125	1.825
Remainder	57	1.245	1.5506	88.387
Differences between steers	19	.....	4.1428	78.712
Final remainder or error in appraisal [a]	38	.505	.2546	9.675

[a] See text for explanation.

Intraclass correlation $= \left(\frac{4.1428}{1.5506} - 1\right)\frac{1}{2} = +0.836$

The "error in appraisal" shown in the last line of Table 2 expresses the variation which would remain in the individual appraisal prices if the appraisers all had the same price level in mind and if the steers were so nearly alike that the average appraisal prices for all the steers were identical. In other words, it is a measure of how much these three salesmen disagreed among themselves. Perhaps an easier way to visualize this difference is to imagine that an infinite number of meat salesmen (of whom the actual three are a random sample) might appraise these carcasses with the same price level in mind. Then the appraisals of each carcass by each salesman would deviate at least slightly from the average of the infinite number of appraisals of that carcass. The figure, 0.505 cent per pound, in the last line of Table 2, is the standard deviation of the difference between one salesman's appraisal of a carcass and the average appraisal of the same carcass by an infinite number of similar salesmen. It may also be considered as the standard deviation of one salesman's appraisals on a group of carcasses which would all have equal average values if appraised by an infinite number of salesmen. In short, it is the standard error of appraisal. It is itself a compound figure measuring both the differences between the ideals of different salesmen and the inability of the same salesmen always to set exactly the same price on carcasses which are identically alike. Which of these two sources of variation is the more important is not revealed by these data.

The intraclass correlation may be considered as a sort of average figure expressing the correlation between the prices set by different salesmen on the same carcasses. It does not measure in actual units the accuracy of the appraisal because it will be higher on groups where there are large differences between the carcasses than on groups where the carcasses show very small differences, even though the appraisers can come within the same number of cents per pound of agreeing with each other in both cases. The intraclass correlation is, however, useful in comparing the unanimity of opinion among the salesmen making the appraisals and the unanimity of opinion among the men using the grading-chart method when both groups of men work on the same carcasses.

One other point requires explanation. The data in Table 1 are treated in Table 2 as if all the steers belonged to a single lot. Each lot or breed might have been treated by itself. The effect of such a treatment would have been to bring all three appraisers to the same

price level for each of the four lots instead of merely bringing them to the same price level for all four lots combined. This would not sensibly have changed the figure for the accuracy of the appraisals *unless* the ideals of the appraisers differed in regard to the desirability of the type of carcass associated with an entire group. With cattle of such distinct types as Herefords or Shorthorns and the Brahman crossbreds, such a difference of opinion was likely to occur. Consequently on every occasion the data were analyzed both lot by lot and as a total regardless of lot divisions. The lot-by-lot analysis eliminated any prejudice for or against an entire lot which one salesman might have had but which was not shared by the other salesmen. The analysis of the totals includes such a prejudice as part of the error of appraisal. The former viewpoint would be most nearly correct for such studies as differences between steers in the same lot, correlations of individual prices within a lot with other measurable characteristics such as weight, previous gain, etc. The accuracy based upon totals seems the most suitable for use in comparing differences between lots or between individual steers belonging to different lots. A lot-by-lot analysis of the data in Table 1 is shown in Table. 3.

TABLE 3.—*A lot-by-lot analysis of the data given in Table 1*

Group	Standard deviation of error in appraising	Intra-class correlation
Herefords	0.548	+0.827
Hereford-Brahmans	.428	+.885
Shorthorns	.408	+.811
Shorthorn-Brahmans	.428	+.750
Average	*.456	

* See text for explanation.

The average standard deviation was obtained by squaring each standard deviation, multiplying these squares by the number of degrees of freedom on which each is based, adding, dividing the sum by the number of degrees of freedom, and extracting the square root of the quotient. This method was followed wherever standard deviations were averaged in this paper. In this particular case there is no conclusive evidence that these appraisers held a different attitude toward the different types of carcasses for, while the figure 0.456 is actually lower than the figure 0.505, the difference does not even approach statistical significance. However, in the grand average of all appraisals on all occasions, this difference, while still of about the same magnitude, does become statistically significant because it is based on numbers so much larger. Thus there is evidence that, on many occasions at least, the appraisers differed significantly among themselves in regard to the relative value of a certain type of carcass characteristic of an entire lot of steers. This of course is not surprising in view of the fact that on every occasion there was at least one lot carrying three-eighths or more of Brahman blood and at least one lot quite free from Brahman blood. In the usual feeding experiment where all the lots are equally divided with respect to

breed and sex, such a difference in the attitude of the appraisers toward certain lots would probably not be encountered.

These appraisals were made on nine different occasions and in three different packing plants. In all, 42 lots of cattle differing in breed or in method of feeding and including a total of 429 steers, were appraised. Besides the steers fed during three years at Kingsville, Tex., the steers used in two years of feeding experiments at Spur, Tex., were included. The weighted average standard deviation of the appraisals for all cattle (after eliminating differences in price level and differences between carcasses) was as follows:

(1) Analysis of each lot of steers separately (based on 786 degrees of freedom)—0.421 cent per pound.

(2) Analysis when all steers slaughtered at one date are regarded as a single group (based on 848 degrees of freedom) —0.467 cent per pound.

The difference between these two figures, although small, is quite significant statistically and is the evidence previously mentioned that on some occasions, at least, the appraisers were not agreed on how to value a type of carcass characteristic of an entire lot of steers.

There was much variation in the size of this standard deviation, which ranged from as high as 0.77 cent in one case to as low as 0.11 cent in another. The only very evident cause of this variation was the degree of precision with which the appraisers worked. The evidence on this point is given in Table 4. If even a single appraisal was given in half cents (as was the case in Table 1) the whole group of appraisals on that occasion was classified as being in half cents. Thus even among the appraisals classified as being made in quarter cents, an unduly large number were given in whole cents or half cents and distinctly less than half of them were given in quarter cents. With this in mind it should be clear from Table 4 that the salesmen were still far from reaching the limits of their appraising ability when they made appraisals in quarters of a cent. In order to get approximately full value out of data, the grouping interval should be at least four times as large as the standard deviation. Even with the finest degree of precision used here, the grouping interval (quarters of a cent) is almost as large as the standard deviation of the error of the appraisal. Apparently these salesmen were so well agreed as to what makes a carcass desirable or undesirable to the trade that the data would have been still more valuable had they appraised the carcasses with a still finer degree of precision; for example, to tenths or sixteenths of a cent per pound.

TABLE 4.—*The relation between precision of appraisals and the size of the errors in appraising*

Precision of appraisal	Degrees of freedom	Standard deviation of error in appraising (cents per pound).	
		Range	Average
In whole cents:			
Lot-by-lot analysis	52	0.53–0.75	0.656
Analysis of total	58	.77	.767
In half cents:			
Lot-by-lot analysis	350	.28– .62	.508
Analysis of total	379	.42– .67	.550
In quarter cents:			
Lot-by-lot analysis	384	.11– .43	.265
Analysis of total	411	.24– .36	.297

COMPARISON OF THE CARCASS-APPRAISAL METHOD WITH THE GRADING-CHART METHOD

On three occasions when 14 lots of cattle totaling 171 head were used the carcasses were not only appraised as described above but were also scored by the grading committee working on the national cooperative project "factors influencing the quality and palatability of meat." Two of these three occasions were during the first year of this grading committee's work, when the methods were still being developed and some of the members of the committee were still somewhat inexperienced in the procedure of grading carcasses. The results must therefore be considered as extremely tentative. The comparison is made at this time because these three occasions are the only ones known to the writers on which both methods were used and there is no definite prospect of further data of this kind becoming available.

In the carcass grading the several members of the committee worked independently, as did the packer salesmen in making their appraisals. The graders examined each carcass both in general and in detail and graded it with respect to each of 40 different characters or points. Conformation, finish, and quality were the general characteristics considered. Compactness, thickness of flesh and external fat, marbling, texture and color of lean, conformation and finish of loin, rib, chuck, rump, and round, and other details were graded. Seven grades—prime, choice, good, medium, common, cutter, and low cutter—with three subgrades in each, were recognized. The total score, representing the grade and subgrade of the carcass, was obtained by adding the numerical values correspondn g to the gradings of the 40 points. The committee grading of the carcass was represented by the average of the total scores of the different members of the committee. This method of judging the market desirability of beef carcasses has the distinct advantage, from the research standpoint, of involving consideration of the inherent causes of the differences and a record of the causes.

The standard deviation of the error in the total score for each carcass, calculated in the same way as described above, was—

Lot-by-lot analysis, based on 361 degrees of freedom—1.71 per cent.

Analysis of totals, based on 386 degrees of freedom—1.80 per cent.

The difference between these two figures suggests that the grading committee, like the salesmen, could not always agree on how to rate a type of carcass characteristic of an entire lot of steers. The difference in this case, however, is smaller and not surely significant, since a difference as large or larger than this could happen by chance alone somewhat oftener than once in twenty times.

Since an average error of 0.421 cent can not be compared directly with an average error of 1.71 per cent, the direct comparison of the degree of agreement among the appraisers and of the degree of agreement in the grading committee was made by comparing the intraclass correlations on the same groups of steers. Such a comparison is shown in Table 5. The average correlations presented in Table 5 are simple unweighted arithmetical averages of the intraclass correlations shown there, and probably should be a little higher because large correlations ought to receive more weight than small ones in a

highly accurate method of averaging and also should be weighted in some manner according to the numbers involved. The intraclass correlations shown were calculated exactly as shown in Table 2 without correction for any bias caused by the smallness of numbers. If properly corrected for this bias these correlations would each be slightly higher than the uncorrected values actually shown.

TABLE 5.—*Comparison of the degree of agreement in the grading committee and the degree of agreement among the packer salesmen*

Group of cattle	Carcasses	Graders	Intraclass correlation of grading committee's carcass grades	Salesmen	Intraclass correlation of salesmen's prices on meat
Second Kingsville:					
A, March slaughter—	*Number*	*Number*		*Number*	
Lot 1	6	4	+0.780	3	+0.860
Lot 2	8	4	+ .424	3	+ .777
Lot 3	8	4	+ .916	3	+ .680
Lot 4	9	4	+ .563	3	+ .731
All steers as a single lot	31	4	+ .638	3	+ .809
B, April slaughter—					
Lot 1	15	3	+ .708	2	+ .609
Lot 2	15	3	+ .846	2	+ .816
Lot 3[a]	13	3	+ .697	2	+ .119
Lot 4	10	3	+ .862	2	+ .862
All steers as a single lot	53	3	+ .790	2	+ .541
Third Kingsville:					
Nos. 1–13	13	3	+.799	3	+ .871
Nos. 14–25	11	3	+.864	3	+ .943
Nos. 26–50	24	3	+.793	3	+ .873
Nos. 51–75[b]	14	3	+.645	3	+ .595
Nos. 76–88	13	3	+.793	3	+ .805
Nos. 89–100	12	3	+.759	3	+ .915
All steers as a single lot	87	3	+ .765	3	+ .875
Unweighted arithmetical averages of—					
14 single lots each calculated separately	171	4 and 3	+ .746	3 and 2	+ .747
3 slaughtering occasions, each calculated as a single group	171	4 and 3	+ .731	3 and 2	+ .742

[a] 1 carcass in this lot was not graded and therefore was also omitted from the price correlation.
[b] 10 carcasses from this lot were graded but were shipped before they could be appraised. Therefore they are also omitted from the correlation of the grades.

It will be seen that on the first occasion the correlation was higher for the salesmen than for the grading committee on the total and on three of the four lots. This was the occasion on which the grading committee had had least experience. On the second occasion the correlation was higher for the grading committee than for the salesmen on the total and on three of the lots and was the same on the fourth lot. The second occasion was the first and only time the price appraisals were secured at a Kansas City plant, and only two men participated. The correlation between their appraisals was distinctly lower than most of the correlations, although there were scattered cases of correlations lower than this for single lots on other occasions. On the third occasion the correlation was higher for the salesmen on the total and on five of the six lots.

From a study of the figures in Table 5 it may be concluded that there was no great difference in the degree of agreement among the

salesmen and that among the members of the grading committee, since the average for the correlations of prices and the correlations of grades are almost identical.

DEFECTS OF THE CARCASS-APPRAISAL METHOD

The appraisal method has some distinct disadvantages, among which are the following:

(1) The price is given for the carcass as a whole and it is therefore impossible to determine from the data whether a low price is due to overweight, insufficient fatness, dark color, "staggy" conformation, or other causes.

(2) The price level in the dressed-beef market is constantly changing, and prices appraised at one time may not be directly comparable with prices appraised a month earlier or a month later. This difficulty could of course be overcome in large part by transforming the appraised prices into some kind of index numbers based on the general price level of the dressed-beef market, but even then there would remain some question as to whether the appraisers were exactly in step with market changes or whether they lagged behind a little.

(3) The price level is slightly different in different markets for different classes of beef. For example, heavy beef is quite unpopular in the Southwest for all except a very limited hotel and club trade, but is in much greater demand in the industrial regions of the Northeast. Moreover, fatness does not usually carry as large a premium in the South as it does in the Northeast. Consequently a lot of heavy fat steers probably would not receive as great a premium over a lot of slightly thinner, much smaller steers if appraised by salesmen familiar only with the country-trade territory around Fort Worth as they would if appraised in Jersey City, N. J., by salesmen familiar with that trade territory.

In view of these defects the appraisal method can not, of course, be recommended where one desires to determine the reasons for a carcass being desirable or undesirable. As a method of describing the details of the individual carcasses the method is useless, but where one wants merely a measure of the desirability or undesirability of the carcass as a whole the appraisal method has the advantage of being inexpensive and reasonably accurate. It also has the advantage (for some purposes) of being readily translatable into differences between the prices of live steers, and hence of permitting, on a somewhat sounder basis than heretofore, the estimation of profits or losses from different methods of breeding, management, or feeding. Both the appraisal method and the grading-chart method possess the very important advantage of enabling the investigator to measure the variation within lots and thus to make an estimate of whether differences in sale prices are significant or accidental.

TRANSLATION OF APPRAISAL PRICES INTO LIVE-WEIGHT PRICES

The simplest method of translating the dressed-meat prices into live-weight prices consists in multiplying the average appraised price for each lot by the number of pounds of chilled beef produced from that lot and dividing the product by the sales weight of the corresponding live animals, or (which is the same thing) multiplying the average appraised price per pound by the commercial dressing per

cent. The figure thus obtained would, however, express only the value of the meat per pound of live weight. With beef cattle the by-products are so important that the beef often sells for less than the live-cattle cost. According to Clemen,[4] meat furnishes only 87.3 per cent of the packer's total revenue from steers, hides furnish 8.6 per cent, and by-products furnish the remaining 4.1 per cent. The problem is further complicated by the fact that costs and profits or losses of the packing company vary not only from plant to plant but from day to day and from lot to lot on the same day. Add to this the fact that the appraised prices for the meat may not actually be realized in the final sale, and it becomes clearly evident that there can be no entirely accurate method of determining what the packer should have paid for the entire shipment in order to obtain a given percentage of profit. It is possible, however, to estimate with a fair degree of accuracy what the differences should have been between the prices paid for the different lots in any one shipment.

Moreover, it is often desirable to express prices, which are based on meat values, at about the same price level as the prices actually paid for the cattle. This can be accomplished roughly by several methods. The simplest (hereafter called method A) is to add to (or subtract from) the meat value per pound of live weight for each lot a constant figure of such size that the unweighted average price for all lots would be the same as the unweighted average price actually paid. In Table 6 are shown the data for four lots of steers marketed in May, 1925, from an experiment at the King ranch, Kingsville, Tex. The meat values average 69 cents per hundred pounds of live weight less than the actual sales prices were. Consequently the corrected sales prices shown under method A are obtained by adding 69 cents to the meat value for each lot. This correction has the effect of making the corrected sales prices average the same as the actual sales prices but adjusts the differences between lots to conform to what was found out later about dressing percentages and about the appraised values of the dressed meat. According to the correction, it appears that the buyer slightly underestimated the price for the Hereford lot and the Shorthorn-Brahman lot or overestimated the price for the other two lots. The difference is not large nor was it so in most cases, but occasionally there were lots on which the buyer seemed to go rather far astray. Doubtless the prices at which the live animals are bought or appraised would be more accurate if one could get averages of prices appraised independently by several buyers and salesmen.

TABLE 6.—*Methods of translating dressed-meat prices into live-weight prices*

Item		Prices of—			
		Herefords	Hereford-Brahmans	Shorthorn-Brahmans	Shorthorns
Average dressed-meat prices	per hundredweight	$15.11	$14.23	$13.38	$14.89
Commercial dressing percentage		57.2	59.4	61.4	56.6
Meat value of live weight	per hundredweight	$8.64	$8.45	$8.22	$8.43
Actual sales price	do	9.25	9.25	8.75	9.25
Corrected sales price:					
Method A	do	9.33	9.14	8.90	9.12
Method B	do	9.33	9.15	8.90	9.11

[4] CLEMEN, R. A. BY-PRODUCTS IN THE PACKING INDUSTRY. 410 p., illus. Chicago. [1927.]

In method B, which is more complicated, the total meat value of the shipment is made equal to the total net proceeds actually received by the shipper. The necessary total correction is divided among the total carcass values for the different lots in proportion to those total values. In method B the correction is a proportion of the meat values per hundred pounds of live weight and is most extreme for the lots having the highest meat value per pound of live weight, while in method A the correction is a flat amount and is the same for all lots. Which method has the more logical basis depends upon whether the buyer of the live cattle makes his mistakes as a general rule on a percentage basis or on a flat basis. For example, if the buyer is just as apt to make a half-cent mistake on an 8-cent lot as he is on a 16-cent lot, then method A is the more accurate. On the other hand, if 1-cent mistake on the 16-cent lot is just as likely to occur as a half-cent mistake on an 8-cent lot, then method B is more accurate.

In determining the general level of the corrected prices method A gives equal weight to all lots whether they contain few steers or many, while method B gives weight to the different lots according to the price and weight of the live cattle in the lot. Method B is thus to be preferred from the accountant's standpoint. Method A would be preferred by the research worker who regards each lot as a representative sample from a very much larger population and conceives it to be only an incidental matter that there were only a few steers in one lot and many in another.

In most cases the two methods agree very closely, but the agreement is unusually close in the example used in Table 6. Both methods are very rough approximations and must compromise on many points. For instance, in obtaining the average dressed-meat price all carcasses in a lot are given equal weight. From the point of view of an accountant it might be more desirable to give more importance to the heavy carcasses and less to the light ones. Such weighting of the average dressed-meat prices was not done in this study. The probable errors of the corrected sales prices shown in Table 7 were obtained simply by multiplying the average commercial dressing percentage of the lot and the probable error of the average dressed-meat prices. Besides that part of the error of appraisal which is not eliminated by using the average of three independent appraisals these probable errors also include the sampling error arising from the fact that the carcasses are not all alike in any lot. This sampling error is much more important than the error of appraisal in nearly all lots included in these studies. The probable errors shown in Table 7 are only very rough approximations, as, for most purposes, one would want also to take into account the additional sampling error arising from variation in dressing percentages within each lot. Nor is the fact taken into consideration that the lots are carefully balanced according to the best judgment of the investigator when the experiment begins. A portion of the variation is thus foreseen and discounted before the experiment begins and should not be included in the real probable error, if there were a reliable method of measuring it. However, if we regard differences of less than twice their probable errors as not requiring explanation and differences of more than four times their probable errors as almost certain to mean a real difference in the market desirability of the two lots, we shall probably not be led very far astray. Certainly we would have a clearer understanding of the

situation than if we used only the actual sales prices and hence had no approximation at all of the probable error of those prices.

TABLE 7.—*Comparison of prices actually paid and prices corrected to conform to appraised carcass prices*

Designation of cattle	Prices per 100 pounds live weight		
	Actually paid	Corrected by—	
		Method A	Method B
	Dollars	*Dollars*	*Dollars*
Kingsville, first year:			
At beginning of experiment—			
Herefords	4.75	5.07±0.21	5.00
Hereford-Brahmans	5.00	4.90± .21	4.87
Shorthorn-Brahmans	4.75	4.55± .13	4.59
Shorthorns	4.00	3.98± .14	4.10
After 120 days of feeding—			
Herefords	8.25	9.08± .05	9.03
Hereford-Brahmans	9.00	8.73± .08	8.71
Shorthorn-Brahmans	8.50	7.99± .10	8.02
Shorthorns	7.75	7.69± .19	7.78
After 179 days of feeding—			
Herefords	9.25	9.33± .04	9.33
Hereford-Brahmans	9.25	9.14± .05	9.15
Shorthorn-Brahmans	8.75	8.90± .04	8.90
Shorthorns	9.25	9.12± .06	9.11
Kingsville, second year:			
At beginning of experiment—			
Herefords	6.00	5.70± .18	5.69
Shorthorn-Brahmans (first cross)	5.00	4.47± .18	4.51
Shorthorn-Brahmans, F_2	6.82	7.53± .19	7.47
Shorthorns	5.95	6.08± .21	6.07
After 120 days of feeding—			
Herefords	9.35	9.45± .11	9.46
Shorthorn-Brahmans (first cross)	9.15	8.94± .07	8.99
Shorthorn-Brahmans, F_2	8.85	9.26± .07	9.28
Shorthorns	9.60	9.30± .06	9.31
After 150 days of feeding—			
Herefords	9.00	8.67± .04	8.67
Shorthorn-Brahmans (first cross)	8.50	8.55± .03	8.56
Shorthorn-Brahmans, F_2	8.50	8.65± .05	8.66
Shorthorns	8.50	8.64± .04	8.64
Kingsville, third year:			
Lot 1, Herefords and Shorthorns	9.00	8.76± .07	8.75
Lot 2, Shorthorn-Brahmans	9.00	9.11± .05	9.10
Lot 3, Shorthorn-Brahmans	9.00	9.20± .05	9.19
Lot 4, Herefords and Shorthorns	8.50	8.43± .04	8.43
Spur, 1924–25:			
3-year-olds—			
Herefords	8.88	8.62± .05	8.62
Hereford-Brahmans	9.00	8.82± .09	8.81
2-year-olds—			
Herefords	7.50	7.95± .06	7.99
Hereford-Brahmans (station bred)	8.50	8.11± .18	8.14
Hereford-Brahmans (purchased)	8.50	8.89± .18	8.88
Spur, 1925–26:			
2-year-olds—			
Herefords	9.50	9.75± .03	9.70
Hereford-Brahmans (first cross)	9.50	9.75± .05	9.70
Back crosses	9.50	9.57± .04	9.52
Yearlings—			
Herefords	10.00	9.89± .03	9.84
Hereford-Brahmans (first cross)	10.00	9.82± .03	9.78
Back crosses	10.00	9.73± .04	9.68
Spur, 1926–27:			
Yearlings—			
Herefords	9.50	9.61± .06	9.58
Hereford-Brahmans (first cross)	9.96	9.65± .06	9.62
Back crosses	10.00	9.61± .06	9.58
Swenson grade Herefords fed—			
Ground milo heads	9.65	10.20± .07	10.19
Entire ration ground	9.73	9.95± .06	9.94
Entire ration unground	9.74	9.56± .07	9.54

Considering the amount of approximation involved in thus translating dressed-meat prices back into live-weight prices, the question may well be raised whether such translation is worth while. In the writers' opinion it is worth while for popular presentation because it combines in one figure the effects of differences in price per pound and differences in dressing percentage. Such translation may not be necessary in technical publications, for the readers of these can keep in mind the separate consequences of dressing percentages and desirability of meat. However, in their studies of Brahman cattle, the writers have usually had to deal with cases where the higher dressing percentages are associated with the lower values per pound of the dressed meat, and in such cases it is not always easy to see at a glance which combination of factors results in the greater market desirability of the live animal.

Table 7 presents the actual and the corrected prices for all the shipments made during three years of cattle-feeding experiments at Kingsville and at Spur, Tex. The probable errors shown for method A might with equal justification have been shown for method B, but in the latter case they have been omitted to prevent the table from becoming needlessly complicated.

Even though the probable errors given in Table 7 are only rough approximations, it seems evident that differences of less than 15 or 20 cents per hundred pounds of live weight can rarely be considered as significant unless they occur again and again each time the experiment is repeated. And yet differences smaller than these have frequently determined the relative profitableness of two lots in published reports of feeding experiments.

In surveying the whole group of data in Table 7 one can not avoid being impressed by the closeness of agreement between the actual prices paid by the buyer for the live animals and the prices which dressing percentages and subsequent appraisal of the dressed meat showed. This general rule has its striking exceptions, however, as in the case of the second shipment during the first year of feeding at Kingsville, where the Hereford lot was very distinctly undervalued. On the contrary, in the final shipment during the second year at Kingsville, the Hereford lot was distinctively overvalued by the buyers. Among the 1925–26 steers from Spur, the 2-year-olds were undervalued and the yearlings were overvalued by the buyer. The previous year the buyers had favored the older cattle slightly more than the younger ones.

A casual survey of the data does not reveal any consistent penalizing of any age or type of cattle, beyond what the appraisal values of the beef justify. The nearest approach to this is in the second year of Kingsville feeding where the double-cross (F_2) Shorthorn-Brahmans were bought at less than their meat value would justify at all three marketings. During the first year at Kingsville, Brahman cattle were overvalued five times and undervalued once. During the second year they were overvalued twice and undervalued four times. During the third year they were undervalued both times. During three years' marketing from Spur, the Brahman lots were overvalued six times and undervalued three times. In all, 13 of the 23 lots containing Brahman blood were overvalued and 10 were undervalued.

The buyer's judgment can not be disregarded entirely, and in cases where he disagrees markedly with the dressed-beef appraisals

it should probably be assumed that the true value lies between the two estimates but much nearer to the estimate of the carcass appraisers. It is concluded from this study that in the carcass-appraisal method we have an inexpensive and much more refined weapon for attacking the problems of the relative market desirability of different lots of cattle than when we merely accepted the sales price as correct. The carcass-appraisal method eliminates the guessing about dressing percentages and how the carcass will appear when dressed. It measures the variation in the desirability of different carcasses in the same lot and thus permits an estimation of the significance of differences between the market desirability of various lots. It seems worthy of much more confidence than the actual live-weight selling price, but the latter should not be entirely ignored.

THE MAGNITUDE OF ERRORS IN LIVE-WEIGHT PRICES

The question is frequently raised whether it would be commercially practical or desirable to sell beef on the basis of dressed weights and grades and thus to eliminate the guessing about dressing percentages and about how the meat will appear when dressed. If such a commercial practice would insure that each individual producer would be paid more nearly on the basis of the quality of the cattle he sells than he is paid at present, it would to that extent be desirable. The data presented herewith have some bearing on this question, inasmuch as they throw light on the accuracy of carcass appraising and grading. They also throw light indirectly on the question of the accuracy of the live-weight prices.

If it could be assumed that the prices given in Table 7 under method A were absolutely correct, then it would develop that the mistakes in the live-weight prices ranged from -83 to $+53$ cents per hundred pounds. If we give equal weight to every lot in Table 7 there will be 45 differences between the live-weight prices and the prices corrected according to method A, but only 35 degrees of freedom, since the corrected prices were so calculated that their average had to equal the average of the actual prices for each of the 10 marketing occasions. The standard deviation of those differences is 34.7 cents per hundred pounds where method A is used as the standard and 33.8 cents where method B is used. But it can not be assumed that the prices arrived at by either method A or method B are absolutely correct. They are subject to a slight standard error of appraisal which theoretically varies inversely with the square root of the number of steers in the lot and the number of appraisers, and which is of about the magnitude of 3 to 4 cents per hundred pounds of live weight on lots of 8 to 12 steers where three men do the appraising. (The error of random sampling among the steers would not be included here.) The standard deviations of 34.7 and 33.8 cents mentioned above are therefore standard deviations of differences and would be reduced slightly if the error of appraisal in the corrected prices could be eliminated. This reduction would be extremely slight, however, if the error of appraisal is anywhere near as low as has been indicated. At all events the standard error of appraising in the live-weight sales price seems to be in these data approximately 30 cents per hundred pounds of live weight or perhaps a little more. Expressed more concretely, this means that if these

data constitute a fair sample of market practice, the buyer buys half of the lots of cattle at within about 20 cents per hundred pounds of live weight of the price which they are really worth. Conversely, half of them are bought at more than 20 cents above or more than 20 cents below their real value on that market. About 5 per cent of them are bought at more than 60 cents too high or more than 60 cents too low. This is done unintentionally and with no desire on the part of the buyer to discriminate against any type or age of cattle. It results solely from the fact that it is impossible for the buyer always to estimate correctly the dressing percentage and the appearance of the dressed meat from live cattle.[5]

SUMMARY

Salesmen employed by packing companies show a high degree of agreement as to what constitutes desirable beef in the eyes of the retail butcher. The standard error of the appraising of a single carcass by one salesman, the market level being constant, ranged from as low as 11.2 to as high as 75.1 cents per hundred pounds of dressed meat on single lots and from as low as 24.4 to as high as 76.7 cents per hundred pounds of dressed meat where an entire shipment of several lots was studied as a single lot. The weighted average of all these standard deviations was 42.1 cents where only a single lot is considered and 46.7 cents where an entire shipment is considered.

A more detailed analysis of these figures shows that these average standard deviations are reduced to 26.5 cents and 29.7 cents, respectively, when we include only those shipments on which the salesmen made appraisals in quarters of a cent per pound. The data suggest strongly that salesmen can appraise meat with a reasonable degree of accuracy to at least as fine a degree of precision as tenths or sixteenths of a cent per pound.

With the usual experimental lot of 10 steers, and with three salesmen appraising independently with a degree of precision at least as fine as quarters of a cent per pound, the findings of this study indicate that the probable error of the accuracy of the average appraisal of the lot would be about 3.4 cents per hundred pounds of dressed meat on the single-lot basis and about 3.7 cents per hundred pounds of dressed meat on the basis of the entire shipment. The appraisal method would therefore be accurate enough to detect differences larger than 10 to 15 cents per hundred pounds in the average value of the dressed meat from two experimental lots of the usual size, if each lot were perfectly uniform.

Additional variation between the carcasses of each lot will nearly always be important enough to require differences greater than 25 cents per hundred pounds of dressed meat in order to demonstrate a

[5] Since the above was written, there have come to the authors' attention data bearing on this same problem in the following publication: EVVARD, J. M., CULBERTSON, C. C., WALLACE, Q. W., and HAMMOND, W. E. ROUGHAGES FOR FATTENING TWO-YEAR OLD STEERS. Iowa Agr. Expt. Sta. Bul. 253, p. [388]–422, illus., 1928. Only seven lots of steers were included. Each lot was credited with the value o the hides, fats, and other by-products produced by it. An average loss to the packer of 45 cents per hundred pounds of live weight was computed from the figures, but this varied from as low as 14 cents for one lot to as high as 83 cents for another. The deviations of these losses from their average were +38, −15, −31, +23, 0, −5, and −8 cents per hundred pounds. Three of the seven deviations exceed 20 cents and the average deviation (neglecting signs) is 17 cents. In view of the small number of lots included, the authors of the present paper regard these Iowa data as quite in agreement with their conclusion that half of the lots of experimental cattle are valued alive at a price more than 20 cents above or more than 20 cents below their real value even if the average price of the entire shipment is assumed to be correct.

significant difference between two lots. Experimental lots so uniform that smaller differences than this would be significant can be imagined, but it is doubtful whether they often occur. Unless the lot is extremely uniform the error of the appraisal is probably of minor importance compared to the variation among the carcasses.

The salesman showed more agreement with each other than the members of the grading committee did on two occasions and less on a third occasion. The unweighted arithmetical averages of all comparable intraclass correlations were almost identical for the appraisal method and for the grading-chart method. The evidence indicates that the salesmen agreed as closely with each other on what constitutes desirable beef as did the members of the grading committee. In view of the relative inexperience of the grading committee when these data were taken, it is reasonable to suppose that subsequent data would show a still closer agreement between the members of the committee.

The appraisal method does not permit analysis to determine why appraisal values are high or low. For this object the grading chart used by the grading committee was especially designed.

The appraisal method is inexpensive, and the writers found the salesmen quite ready to cooperate in the appraisals after they thoroughly understood the purpose of them.

By the appraisal method it is possible to express the results on the basis of live-weight prices. For such translation several methods may be used. Each involves some assumptions which make the translated prices only approximate.

A comparison of the translated prices with the actual sales prices reveals a rather close general correspondence, but occasional instances occur where the actual sales prices were far from corresponding to the value of the meat. Such unjustified sales prices seem to arise from errors in the salesmen's or buyers' judgment and not from any consistent prejudice on the part of the buyer for or against any type, age, or breed of cattle. The standard deviation of the differences between the prices actually paid and the corrected prices is 34.7 cents per hundred pounds when method A is used for correcting and 33.8 cents when method B is used. After making allowance for the small error of appraising in methods A and B, it appears that the standard error of appraising in the actual live-sales price of experimental lots of steers is about 30 cents per hundred pounds of live weight. For comparison with other experimental lots in the same shipment, buyers are within about 20 cents per hundred pounds of the correct price for half of all their purchases. Errors greater than 60 cents per hundred pounds of live weight occur in only about 5 per cent of the lots.

○